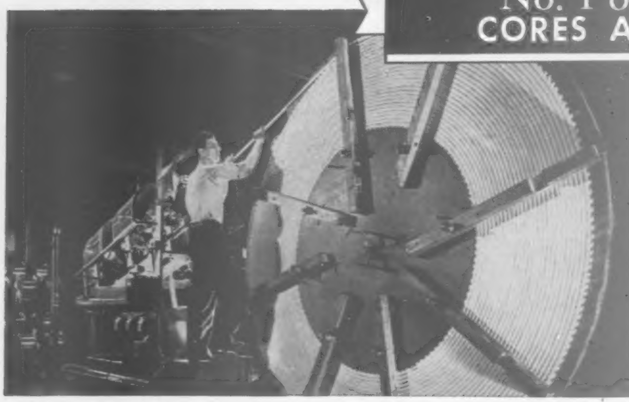
ALLIS-CHALMERS

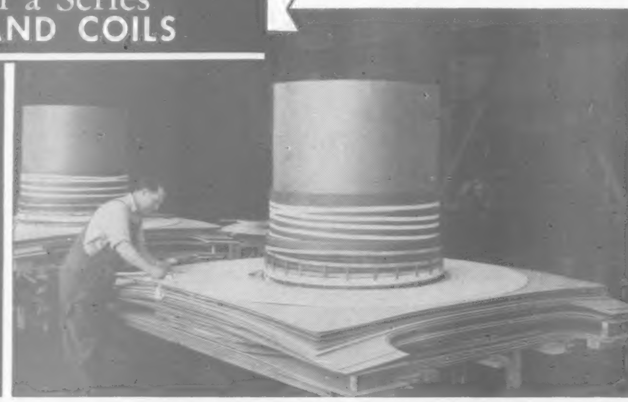
Electrical REVIEW

4th Quarter, 1946

How Allis-Chalmers Builds Quality Into Your Power Transformer

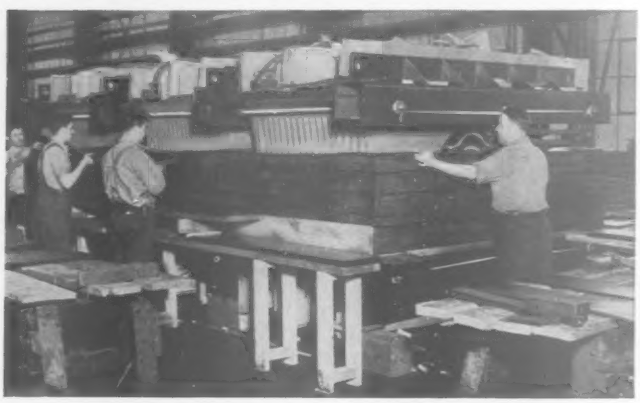
No. 1 of a Series
CORES AND COILS

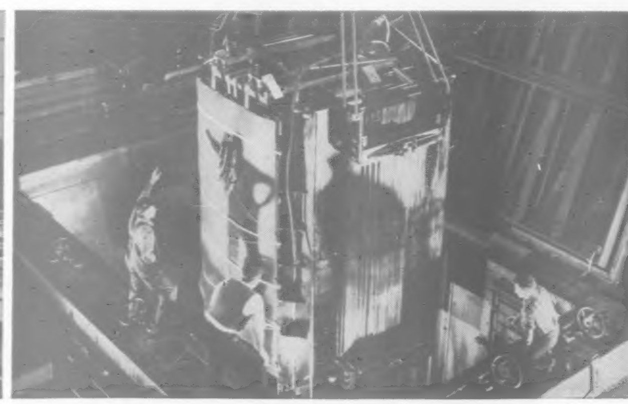




1. WINDING COILS is one of the first steps. Circular coils are easy to wind with uniform tension and are the least subject to deformation stresses under short circuit conditions.

2. COILS AND INSULATION are built up on a solid foundation tube. Spacers are used on the insulation sheets to support safely the windings without affecting the free flow of transformer oil.





3. CORE IRON stacked and interleaved. Laminations are sheared from highest grade non-aging silicon steel with care taken to eliminate burrs. Each sheet is annealed to lower losses, then varnished.

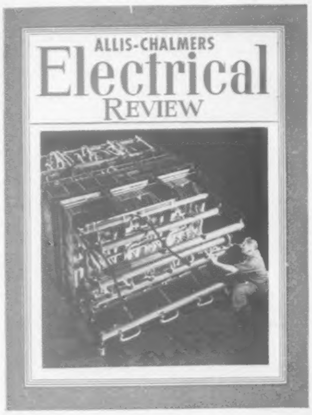
4. BEFORE OIL IMPREGNATION, the transformer core and coil assembly is lowered into a large vacuum tank, where it is thoroughly dried out by the application of heat and vacuum.

ALLIS-CHALMERS has played and will continue to play an important role in transformer development, always seeking the greatest possible perfection in design and manufacture. The records of dependable service and performance of the many Allis-Chalmers power transformers in service coupled with more than forty years' experience in the designing and building of transformers to serve every power, industrial and utility need bear out this leadership in the transformer field. For a more detailed story on how your power transformer is built, write for Bulletin B6402. ALLIS-CHALMERS, MILWAUKEE 1, WISCONSIN. A 2162

1847 1947 A CENTURY OF SERVICE to Industry THAT MADE America Great

ALLIS-CHALMERS

One of the Big 3 in Electric Power Equipment — Biggest of All in Range of Industrial Products



CORE AND COILS for one of the highest voltage mobile substations ever built are undergoing final assembly before placing in forced oil-cooled tank. The substation, to be trailer mounted, will furnish 2500 kva at 2.4 kv to 13.8 kv from 31 kv to 110 kv, three phase line. Tertiary winding provides 5 kv. When finished the substation will provide complete emergency tie-in facilities for a large west coast network. A story on trends in mobile substations will appear in the first quarter, 1947, Review.

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ALLIS-CHALMERS Electrical REVIEW

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Contents

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UTILITIES AND INDUSTRY have become increasingly noise-conscious in recent years. Even normally quiet equipment such as transformers are designed to operate at low decibel levels, particularly where the installation is made in heavily populated areas. Sound level readings taken at various points have become standard test floor procedure. Here readings are being taken on a 10,000 kva, 33,000 volt three phase transformer.

Control That Speed!

PART V

Concluding this series the authors describe the Scherbius and LeBlanc systems and review pros and cons of the five main types of variable speed drives.

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G. BYBERG and E. H. FREDRICK
Motor-Generator Section — Allis-Chalmers Mfg. Co.

TWO of the preceding articles in this series have discussed adjustable speed systems in which the induction-frequency-converter principle of the main drive wound rotor induction motor is utilized in combination with direct current speed-regulating equipment.

There are two other well known systems, occasionally used for large drives, utilizing the same frequency converter principle, but in conjunction with polyphase commutator type alternating current speed regulating or frequency converting machines. These are the Scherbius and the LeBlanc systems of speed control.

The speed range of these systems is definitely determined by the characteristics and commutating limitations of the a-c commutator machines and, since the practical commutation limit is on the order of 15 to 18 cycles, it will be evident that the higher the frequency of the main power supply the smaller will be the percentage speed range obtainable. For example, on a 25-cycle system a speed range of 18/25 or 72 percent is possible. This range is generally sufficient for the average drive to which these systems are applicable and hence it may be said that they are eminently suitable for the lower frequencies.

However, the majority of the world's power systems are now, or being changed to 50 or 60 cycles. On a 60-cycle system the maximum percentage speed range would be 18/60 or 30 percent, and on a 50-cycle system 18/50 or 36 percent. Most adjustable-speed constant torque or constant horsepower drives are not satisfied by these limited speed ranges.

Both systems built "double-range"

For this reason both of these systems are usually built as "double-range," i.e., designed to operate with the same percentage speed range above and below the synchronous speed of the main drive motor. The double-range characteristic need not, therefore, be considered a special feature built into the systems for better operation, but may be considered as a necessity imposed upon them by the limitations mentioned above. As will be seen, the double-range feature actually imposes the use of additional machines for its accomplishment in one system, while in the other system no additional machines are required.

As has been pointed out in previous parts of this article, in any system employing the induction-frequency-converter principle of the wound rotor induction motor as a means for speed control, the control (slip) power taken from the motor collector rings is converted to a form usable by another machine which is either direct connected to the main motor shaft or capable of returning the power to the line. The slip power will decrease, of course, as the main wound rotor motor speed approaches its synchronous speed and at synchronous speed the power flow would cease entirely, since no voltage is induced in the secondary winding under this condition.

However, if current could be maintained in the rotor winding at synchronous speed by external means, the motor would develop torque proportional to this current and operate as a synchronous motor as long as this current (d-c, at zero frequency in rotor) flows in the rotor winding.

If, then, this superimposed rotor current could be made to alternate gradually at a very low frequency and with a phase rotation opposite to that of the normal slip frequency, the motor could be accelerated above synchronous speed, i.e., to have negative slip. Obviously, then, if the rotor current can be controlled in this manner, the main drive can be operated through the main motor's synchronous speed and above that value, or in other words, made double-range.

LeBlanc "frequency converter" system

The basic principle of the LeBlanc system (sometimes referred to as the frequency converter system) is that the low frequency of the wound rotor motor secondary is converted to a higher frequency by means of the polyphase commutator type frequency converter. In construction, this frequency converter armature is similar to that of the synchronous converter, having a commutator with three or six brush studs per pole and three or six collector rings, depending on whether the supply is three or six phase. As in the synchronous converter, the voltage at the collector rings is directly dependent on the voltage impressed at the commutator and independent of the speed of rotation.

In this system the stationary part of the frequency converter has no winding since it merely provides a part of the magnetic circuit in order to reduce the magnetizing current required. Whether in a constant torque or constant horsepower system the converter always has the same number of poles as the motor driving it.

The frequency which appears at the collector rings is a function of the actual speed of rotation and the relation it bears to the speed of rotation of the magnetic field due to the impressed frequency at the commutator. In other words, it is the algebraic sum of the applied system frequency and the slip frequency of the main drive wound rotor motor. To better illustrate this, let us first consider the two types of drives to which the system may be applied, namely, the constant torque and the constant horsepower unit, and the machines required for each.

In Figure 1 is shown the constant horsepower drive for which the system is most suitable. Basically, we have the conventional wound rotor motor, A, the frequency converter, B, driven by a constant speed synchronous motor, D, and feeding into the speed-regulating synchronous motor, C, the latter solidly connected to the main wound rotor motor shaft.

The frequency at the collector rings of B must obviously be the same as that required by C at any given point of reduced speed. Assume that main drive wound rotor motor, A, has a synchronous speed of 300 rpm at 60 cycle and therefore has 24 poles. Then the synchronous motor, C, must also have 24 poles. At 20 percent slip on A, the slip frequency, sf, delivered to B is 12 cycles and the speed of A and C is 240 rpm (one-fifth speed reduction). To drive the 24-pole synchronous motor at 240 rpm requires 48 cycles from the collector rings of the frequency converter.

Assume further that the frequency converter is driven by a constant speed synchronous motor, operating on the same 60-cycle system as the main wound rotor induction motor, and that the slip frequency from A is connected to the converter in such a manner that the field produced rotates at one-fifth speed in the same direction as the converter armature rotation. Then the frequency at the collector rings of the converter must be the algebraic sum of $-$ sf and $+$ f and, in this case, $-12 + 60$ or 48 cycles which is the required frequency for C.

The main wound rotor motor is chosen of a speed midway between the required maximum and minimum speeds. Hence, using the same example, at synchronous speed of 300 rpm the current in the wound rotor secondary is d-c, or frozen a-c, and the frequency at the collector rings of the converter is 60 cycles. As the speed increases above synchronism the field of the converter begins to rotate in the direction opposite to that of the converter armature rotation and at 360 rpm on the main drive unit the converter collector ring frequency is $+12 + 60$ or 72 cycles, which is that required by the 24-pole synchronous motor for 360 rpm.

As stated above, there is no voltage transformation in the converter, but as the field excitation on C is changed, its voltage and that at the converter changes so that the speed of the wound rotor motor must adjust itself to the point where the secondary current corresponds to the load torque.

Some power factor correction possible

The system lends itself to a certain amount of power factor correction. This is accomplished by changing the brush position on the converter commutator, and changing the phase relation between the converter and the main wound rotor motor secondary voltages. Or the frequency converter driving motor, D, may be built with a distributed type field winding and controlled by varying the excitation in this winding by means of a special field rheostat to change the magnetic center line of its poles. In other words, this motor is provided with a magnetic phase-shifting device, which makes it a special machine.

The relation between the rating of the main drive induction motor and the secondary speed regulating machine for a constant horsepower drive is shown in Figure 2. For example, a drive having a rating of 2000 hp, 60 cycle, with a speed range of 450 to 252 rpm, could use a main drive wound rotor motor having a basic speed at the midway point of the speed range or 360 rpm. This provides a speed range of 30 percent below and above the basic 360 rpm speed with a secondary frequency range of 18/0/18 cycles. Neglecting the losses, the frequency converter and the synchronous motor would each have to be good for 600 hp, with a frequency range of 42 to 78 cycles for the latter and a base speed of 252 rpm. Note that a speed range of 30 percent below and above does not provide a 2:1 ratio, but only 1.85:1. To obtain 2:1 ratio would require $33\frac{1}{3}$ percent below and above which would result in 20 cycles on the converter, which is beyond the practical range for good commutation.

The system can also be built for constant torque operation. In that case, the frequency converter is direct-connected to the main drive motor and power is returned to the line through a system of tap-changing transformers. The power returned to the line must have the same frequency as the line, hence the converter obviously must have the same number of poles as the main drive wound rotor motor. Because the usual application for this type of drive is of the low speed class, it becomes impractical for reasons of cost. The converter must be good for full capacity at reduced speed and would generally mean the complete development of a new machine for each application.

The system does, however, have certain advantages, such as the relatively small size of the auxiliary machines. The main disadvantage is its dependence upon the commutation of the frequency converter and the fact that frequency converters have not been built in sufficient quantities to become standardized. The synchronous motor is in a sense somewhat special in that it must be designed electrically for the low speed and mechanically for the maximum speed.

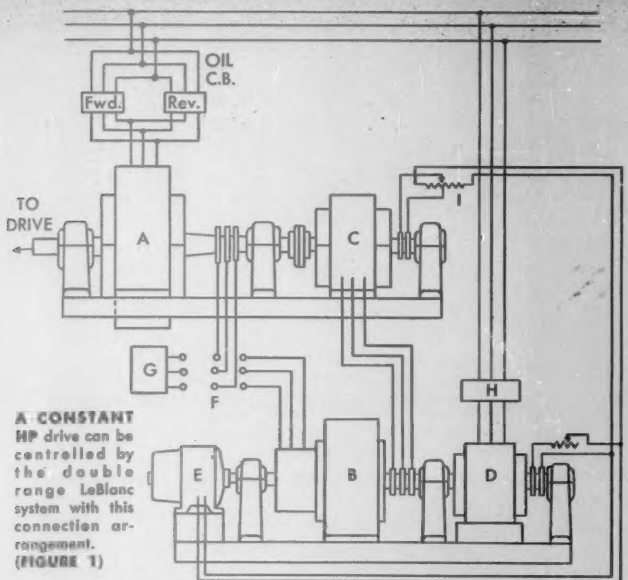
Scherbius machine regulates system

The Scherbius system has, in the past, been applied to a large number of metal-rolling mill installations but the stringent requirements of fast, accurate control of speed in the modern mill has caused the Scherbius units to be supplanted for these applications by the relatively more expensive straight d-c variable voltage systems.

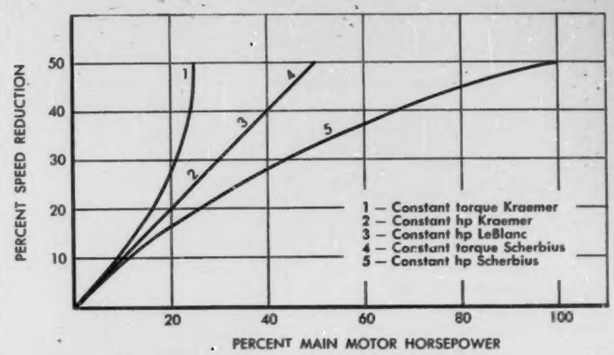
This system makes use of the fact that a direct current generator can be made to act as a frequency converter if its field is excited with a low frequency alternating current, the voltage generated being of the same frequency as the excitation and of a magnitude dependent upon the speed and flux in the machine. In order to obtain a generated voltage of exactly the slip frequency of a wound rotor motor, a d-c generator excited from the collector rings of the wound rotor motor could be used.

An ordinary d-c machine would have several disadvantages. First, it would develop only a single-phase voltage; by spacing the brushes 120 electrical degrees apart three-phase voltages could be obtained. Secondly, since the excitation is the three-phase supply of the wound rotor secondary, its standard field structure is unsuitable. The field structure must therefore be constructed similar to that of the stator of an induction motor or a synchronous machine.

A machine operating on the above principles, known as the Scherbius unit and giving the system its name, is the regulating machine for the system. Unlike the frequency converter in the LeBlanc system, this regulating machine has distributed three-phase field windings consisting of the main exciting



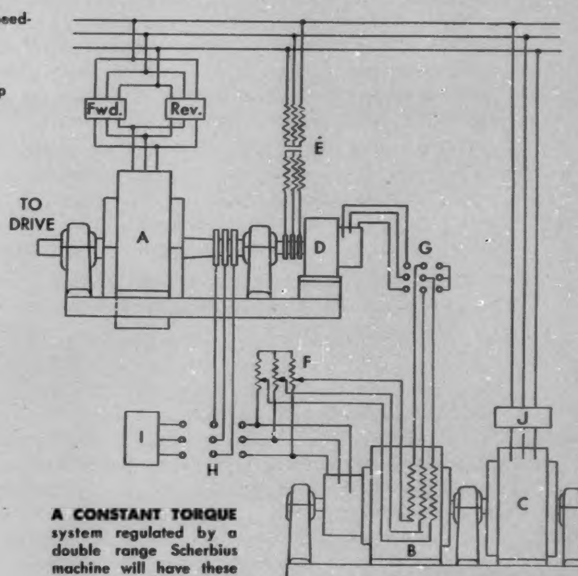
A CONSTANT HP drive can be controlled by the double range LeBlanc system with this connection arrangement. **(FIGURE 1)**



FIVE SYSTEMS are compared to show relation between rating of the main drive induction motor and secondary speed regulating machine for representative adjustable speed hp drives. **(FIGURE 2)**

A — Main wound rotor induction motor
B — Three-phase commutator type frequency converter
C — Speed regulating synchronous motor
D — Synchronous motor driving E and supplying losses in B
E — Exciter for synchronous motors
F — Transfer switch
G — Starting duty resistor
H — Starter for synchronous motor D
I — Speed regulating field rheostat

A — Main wound rotor induction motor
B — A-C commutator type compensated speed-regulating machine (Scherbius)
C — Induction motor or generator
D — Ohmic-drop exciter
E — Step-down transformer for ohmic-drop exciter
F — Tap-changing field control auto transformer
G — Field switch
H — Transfer switch
I — Starting duty resistor
J — Induction generator control



A CONSTANT TORQUE system regulated by a double range Scherbius machine will have these connections. **(FIGURE 3)**

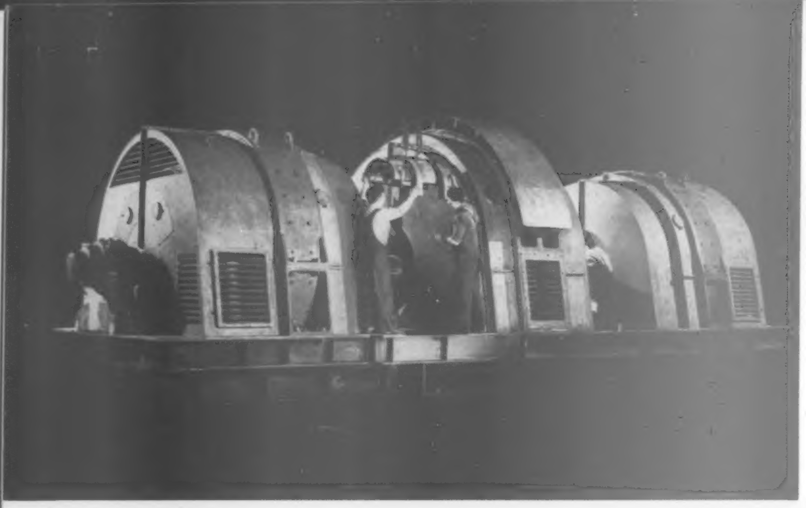
field, interpole and compensating field windings. The connections in the double-range constant torque type system are shown in Figure 3.

The regulating machine, as seen from the diagram, receives both its armature current and field excitation from the wound rotor motor collector rings. Hence, its frequency will be established and governed by the slip frequency of the wound rotor motor. Since the speed of the regulating machine is held substantially constant by the induction generator (or motor) C, the magnitude of the generated voltage is responsive only to field strength which, in turn, is subject to adjustment through the auto-transformer F connected in the field circuit.

"Ohmic drop" exciter added

To permit operation up to and through synchronous speed, a machine commonly called an "ohmic drop" exciter, D, is added to the circuit. This ingenious device is not actually an exciter but rather a mechanical frequency-converter. Connected to the main motor shaft, its speed, of course, corresponds to that of the main motor and its construction is similar to that of the frequency converter in the LeBlanc system in that it has an armature winding but no field windings. Its armature winding is connected by a set of slip rings and through a three-phase transformer to the constant frequency main supply system. Three-phase output from its commutator supplies the field circuit of the regulating machine during this range of operation.

The armature winding merely serves as a balance coil between the input and output and, since the machine has no field windings, generates no voltage. In operation, the frequency appearing at the commutator is obviously a function of the slip at which the motor is running. At synchronous speed of the main wound rotor motor, the device acts as a rectifier and the d-c output is fed to the field winding of the regulating machine, enabling that machine to develop a voltage which will cause a direct current to flow in the rotor winding of the main wound rotor motor. If this current is greater than that required to develop the torque required by the load, the main motor will accelerate through synchronous speed, where the initial regulating scheme again becomes gradually effective as the supply from the ohmic drop exciter assumes frequency and as the voltage across the ring again becomes sufficient to supply excitation for the regulating machine.



TYPICAL OF THE MOST WIDELY USED UNITS for adjustable speed drives of large size is this three machine motor-generator set which is used in the adjustable armature voltage system. After balancing and testing, for which the unit is being assembled, it will be installed as part of a speed control system for a metal rolling mill.

It becomes evident that the ohmic drop exciter is required only when operation is at or very near synchronous speed, or to allow the main drive wound rotor motor to accelerate through synchronous speed.

When operating below synchronous speed the regulating machine acts as a motor and drives the induction generator, C, returning power to the line. When operating above synchronous speed the induction machine, D, drives the regulating machine as a generator.

This system is essentially and best suited to constant-torque applications. It can be built as constant horsepower but here it has the same disadvantage as the constant-torque LeBlanc system, namely, the regulating machine must be of the same speed and of the same number of poles as the main drive wound rotor motor.

Pros, cons of five systems

In summarizing the advantages and disadvantages of the various systems described, the major points of consideration outlined in the first article must be reviewed. It is obviously impossible to state that for any particular drive only one particular system is applicable except where experience has indicated for certain kinds of applications that only a particular type is practicable. For example, for drives involving continuous process operation, such as hot-strip mills or sectionalized paper machine drives where perfect production is dependent upon the absolutely correct relative speeds of successive motors, or in the case of reversing mills where speed of reversal is paramount, the selection of a direct current drive is a foregone conclusion. Contrariwise, there is no set rule by which one may say that a Kraemer, LeBlanc, or Scherbius should be used for a single stand merchant mill or a constant torque Kraemer or variable induction-frequency-converter system should be used for a propeller testing system. In many cases of large drives one or more systems may be applicable and the individual case must be determined on its merits.

Each individual system has, however, certain marked advantages and disadvantages depending upon (1) speed range possible, (2) speed regulation, (3) simplicity or complication of control, (4) overall operating efficiency, (5) overall first cost, including installation, (6) dependability as determined by the number and types of machines necessary, and (7) maintenance.

The relative speed range possibilities have just been discussed.

As far as speed regulation is concerned, the d-c drive heads the list but, with the advent of the rotating type regulators, the other types are able to follow in close order.

The straight d-c drive again heads the list when it comes to relative simplicity of control. In other types the control will be dependent to some degree on the number of the secondary speed regulating machines required. In actual operation there will be little more difficulty since most controls of this type are designed to make operations in their required sequence fully automatic.

When it comes to overall operating efficiency the straight d-c drive will generally lag behind the rest because all machines are successively of full size. The generator must be of the full motor capacity plus the latter's losses. The synchronous motor driving the generator must be good for the full motor capacity plus the losses in the d-c motor and generator. In most other types the secondary regulating machines are a certain percentage of the main drive motor capacity (see Figure 2), so that the total "hp per rpm" of all the required machines is usually considerably less than the corresponding total for the straight d-c drive.

First cost depends on needs

The relative first cost is something which can only be definitely determined after the requirements are known. The first cost of straight d-c drives is usually somewhat higher, excepting where the secondary regulating machines are considerable in number and of special nature.

Dependability is also something which in many cases is directly dependent upon requirements. For example, a low speed machine is usually less a source of trouble than one which is designed for the extreme upper limits of speed for the particular rating and type. On the other hand, the greater the number of secondary regulating machines a particular system requires, the more is its dependability reduced, all other things being equal. Also, if machines are of a special nature the reliability of the system as a whole may be further reduced.

The question of maintenance hinges on the number of machines, their speed, the number of bearings and commutators involved as well as the necessary provisions in the control to prevent improper operation of the equipment.

Most large drives are generally of such importance that it will be advisable to consider several systems, wherever this is permissible, in order to arrive at the most satisfactory drive. The final selection usually represents a compromise in which certain desirable features of one system may be sacrificed to gain more advantageous characteristics in another.

Is it Sound...or Noise?

PART I OF TWO PARTS

L. C. AICHER
Transformer Section,
Allis-Chalmers Mfg. Co.

Measuring and evaluating sound has become a field of engineering by itself. To bring you up-to-date, the fundamentals of sound in industry are outlined.

NOISE reduction is an ever-present problem in modern living. Psychological and physiological studies have shown that high noise levels decrease the productivity of all workers and, in many instances, the vibrations which produce noise also affect the life or efficiency of a machine.

Conversely, there are occasions when loud sounds are desirable. A few years ago it was necessary to design air-raid sirens so they could be heard by people engaged in their daily activities, sometimes in locations where there were high background noise levels to be penetrated.

Knowledge in the field of sound and noise reduction has grown so much since the advent of talking pictures and radio that it has become a study in itself known as acoustics. This article will review the basic principles of sound and a succeeding article will discuss the means an engineer, faced with noise problems, has available to assist him in studying noise.

"Does one have to be present to hear in order that there be sound?" The answer depends upon our viewpoint of sound. Physiologists, psychologists, and otologists are chiefly interested in the sensation of sound (the hearing mechanism, hearing process and auditory sensation). This is subjective sound, defined as "an auditory sensation resulting from the action of an external disturbance upon the ear and its associated nerve endings."

Engineers, akin to physicists and acousticians, are primarily interested in the external disturbances that produce sound. This is objective sound and is defined as "a physical disturbance (of vibratory character) in an elastic medium which would be capable of producing an auditory sensation if received by an ear."

The American Standards Association prefers to define objective sound as "an alteration in pressure, particle displacement or particle velocity propagated in an elastic material or the superposition of such propagated alterations."

What is noise?

Some sounds are undesirable because:

They may mask other desirable sounds such as speech or music.

They may have an injurious effect upon the nervous system.

They may produce mechanical failure of devices by forced vibrations through any media.

In warfare, they may reveal the location of friend or foe.

All these have one thing in common — they are undesirable. The ASA definition states "Noise is any undesirable sound."

Sound waves, like all waves except electromagnetic waves, possess these familiar characteristics:

a. They require a medium for their propagation.
b. They have finite velocity.
c. They are reflected.
d. They are refracted.
e. They are diffracted.
f. They interfere.

If we are to describe a sound wave we must give:

a. The wave form. If not of sine wave form then its harmonic series must be given.
b. The frequency.
c. The amplitude.
d. The wave length.

Many of us rely upon our knowledge of music for our characterization of sound, but since music is written and produced for its physiological effect, a clarification of terms is needed to avoid any confusion. The sensations of sound and their physical correspondents are:

a. Pitch — a subjective characteristic of frequency and influenced by intensity.

b. Loudness — a subjective characteristic depending upon the sensitivity of the ear, the size of the pressure variations in the sound wave, and the frequency of the sound.

c. Quality — depends upon the number and relative prominence of the overtones added to the fundamental.

The more important fundamental terms used in the measurement of sound and its characteristics are arranged in Figure 1. Physical quantities are listed first. These do not depend upon the human ear. Next are physiological quantities involving the human ear. The last is the quantity measured by the sound level meter.

Sound wave is longitudinal

Simple harmonic waves are waves of such nature that the particles of the medium through which they travel oscillate with simple harmonic motion. The most familiar waves are

those in which the particles oscillate along lines perpendicular to the direction of propagation of the wave, and are called transverse simple harmonic waves.

In sound waves, on the other hand, the particles oscillate along the line of propagation of the wave and are called longitudinal simple harmonic waves. Figure 2 illustrates a longitudinal wave and what is meant by displacement amplitude. The row of circles between A and A′ represents particles of a medium along the line of propagation before the membrane MM′ has been distorted. Some force has set the membrane into oscillitory motion such that its maximum distortion from its equilibrium position is "y_m" (dotted line). This motion is transmitted into the medium and pushes particles in the elastic medium along the line of propagation by various amounts, y_1, y_2, etc. The maximum displacement of any particle in free space is equal to the maximum distortion of the membrane and is "y_m," the displacement amplitude. The curve along CC′ shows the wave form of the displacement amplitudes and curve DD′ shows the instantaneous sound pressure wave form. Curve EE′ shows the particle velocity wave form and FF′ the acceleration wave form. It is evident that in the case of longitudinal waves, the shape of the medium is not similar to the wave curve, but instead, the wave is propagated in the form of compressions and rarefactions in the medium.

NOMENCLATURE

- a = acceleration, cm/sec^2
- d = distance from center of sound source to point in question, cm.
- f = frequency, cycles/sec.
- p = effective sound pressure, dyne/cm^2
- p_m = maximum sound pressure, dyne/cm^2
- r = radius of sound source, cm.
- t = function of time, sec.
- v_m = particle velocity, cm/sec.
- x = distance from origin to equilibrium position, cm.
- y_m = particle displacement amplitude, cm.
- D = density, grams/cm^3
- D_{dg} & D_{wg} = density of dry and wet gases respectively, grams/cm^3
- I = sound intensity, ergs/sec. cm^2
- K = modulus of elasticity
- P = atmospheric pressure, cm of mercury
- R = acoustic resistance, ohms
- T = period of one wave cycle, sec.
- T_1 & T_2 = absolute temperature, °C.
- V = wave velocity, cm/sec.
- V_{t_1} & V_{t_2} = wave velocity associated with temperature, cm/sec.
- V_{dg} & V_{wg} = wave velocity associated with dry and wet gases respectively, cm/sec.
- γ = ratio of specific heat of a gas at constant pressure to that at constant volume. (1.40 for air)
- λ = wave length, cm.
- ϕ = angle between point in question and plane of vibration, radians.

Sound waves can be emitted in spherical or cylindrical form as well as plane waves, but since most objects in industry where noise is a real problem are of considerable size, they can be compared with spheres of considerable radius, sufficiently so to justify using the much more readily manipulated plane wave analyses. This is particularly true where measurements and analyses are made at small distances from the machine compared with the dimensions of the machine. A column of relationships for plane sound waves is included in Figure 1.

Sound wave elements

The *particle velocity* in a sound wave is the instantaneous velocity of a given infinitesimal part of the medium, with reference to the medium as a whole, due to the passage of the sound wave. Particle velocity, v_m, must not be confused with wave velocity, V. (See nomenclature in previous column.)

The *velocity level* of a sound, in decibels, is twenty times the logarithm to the base ten of the ratio of the particle velocity of the sound to the reference particle velocity, 5×10^{-6} centimeters per second, root mean square.

The *maximum sound pressure* p_m, for any given cycle, is the maximum absolute value of the instantaneous sound pressure during that cycle.

The *effective sound pressure* p, at a point is the root-mean-square value of the instantaneous sound pressure over a complete cycle at that point.

The *pressure level* of a sound is twenty times the logarithm to the base 10 of the ratio of the pressure p of this sound to the reference pressure p_o, where the reference pressure is 0.0002 dyne per square centimeter.

The *sound intensity* of a sound field in a specified direction at a point is the sound energy transmitted per unit of time in the specified direction through a unit area normal to this direction at the point. The unit of sound intensity is the erg per second per square centimeter, but sound intensity can also be expressed in watts per square centimeter.

The *intensity level* of a sound is ten times the logarithm to the base ten of the ratio of the intensity I of this sound, to the reference intensity I_o. Unless otherwise specified the zero level or reference intensity is 10^{-16} watts per square centimeter. This is equivalent to a reference intensity of 10^{-9} ergs per second per square centimeter.

Loudness is that subjective quality of a sound which determines the magnitude of the auditory sensation produced by that sound.

The *loudness level* in phons of a sound is numerically equal to the intensity level in decibels of the 1000 cycles per second pure tone which is judged by listeners to be equivalent in loudness.

Sound level is the quantity measured by a sound level meter and is a "weighted" sound pressure level.

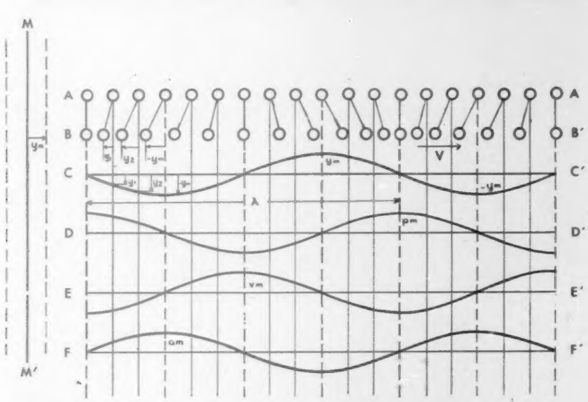
The ear as a sound receiver

Whether a sound is objectionable or not can only be ascertained by a human ear. No attempt will be made to describe the ear from the physiological viewpoint. Instead, a comparison of the principal features of the ear as a sound receiver to the corresponding action of a microphone should help in understanding how it has been possible to develop a practical basis for an investigation of the hearing process.

Sound pressure is the excitation for a microphone and

Relationship of Plane Sound Waves. **(FIGURE 1)**

Term	Type	Symbol	Relation for a plane wave $y = y_m \sin 2\pi f\left(t - \frac{x}{V}\right)$	Unit
Displacement Amplitude	Physical	y_m	$y_m = \frac{v_m}{2\pi f} = \frac{p_m V}{2\pi f \gamma P}$	cm.
Particle Velocity	Physical	v_m	$v_m = 2\pi f y_m = \frac{p_m V}{\gamma P}$	cm/sec.
Velocity Level	Physical	db	$db = 20 \log_{10} \frac{v_m}{5\sqrt{2} \times 10^{-6}}$	decibel
Maximum Sound Pressure	Physical	p_m	$p_m = \frac{2\pi f y_m \gamma P}{V} = v_m DV$	dyne/cm²
Effective Sound Pressure	Physical	p	$p = \frac{p_m}{\sqrt{2}}$	dyne/cm²
Pressure Level	Physical	db	$db = 20 \log_{10} \frac{p_m}{2.04\sqrt{2} \times 10^{-4}}$	decibel
Sound Intensity	Physical	I	$I = 2\pi^2 f^2 y_m^2 DV$	erg/sec. cm²
Intensity Level	Physical	db	$db = 10 \log_{10} \frac{I}{10^{-9}}$	decibel
Loudness	Physiological (descriptive)	L. U.		Loudness Unit
Loudness Level	Physiological (relative)	Phon		Phon
Sound Level	Measurement	db		decibel



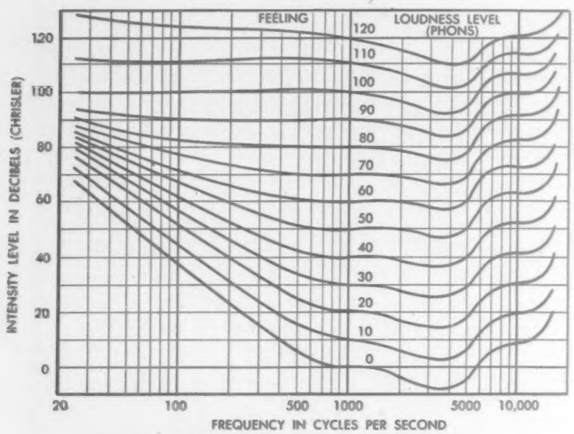
SOUND WAVES are longitudinal where displacement amplitude at A is $y = y_m \sin \frac{2\pi t}{T}$. The motion of any other particle, equilibrium position of which is x from origin, is $y = y_m \sin\left(\frac{t}{T} - \frac{x}{\lambda}\right)$. But $f = \frac{1}{T}$ and $\frac{V}{\lambda}$, so general displacement amplitude is $y = y_m \sin 2\pi f\left(t - \frac{x}{V}\right)$. **(FIG. 2)**

the response is electromotive force. Both excitation and response are physical quantities. In the ear, the excitation is also sound pressure but the response is sensation. The excitation is a physical quantity, but the response is entirely subjective.

Microphone output is expressed in millivolts response per dyne per square centimeter of incident pressure. Furthermore, microphones are constructed so the sensitivity is independent of power input and of rather wide limits of frequency.

An expression for the mental response of the ear in units of sensation, as a function of the physical stimulus, is difficult to formulate for two reasons. The sensitivity of the ear, in units of sensation per unit of stimulus, is not independent of frequency within the limits of audibility, nor is it independent of the size of the stimulus. Nevertheless, it has been found that knowing the frequency and the intensity of the sound impinging the ear, it is possible to find a number that is approximately proportional to the magnitude of the sensation, that is to the loudness of the sound.

The Weber-Fechner law is an accepted rule of psychophysics and applies within limits to all the sense organs. It requires that "equal increments of sensation are associated with equal increments of the logarithm of the stimulus." If this law applies to the ear, then loudness is closely associated with the logarithm of intensity. This logarithmic relation between loudness and intensity has given rise to the logarithmic method of expressing sound intensities. The measure of intensity is called the "intensity level" and the unit of intensity level is the "bel."



LOUDNESS CONTOURS above are representative of the average human ear, and show that the ear has a limited frequency response range. (FIG. 3)

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The bel is defined as the fundamental division of the logarithmic scale for expressing the ratio of two amounts of power, and is:

$$n = \log_{10} \frac{P_1}{P_2} \quad \ldots\ldots (1)$$

A bel is a rather large unit so a more practical smaller unit, the decibel, has been adopted and is equal to one-tenth of a bel, thus:

$$n = 10 \log_{10} \frac{P_1}{P_2} \quad \ldots\ldots (2)$$

The abbreviation db is commonly used for the term decibel.

A method of loudness determination has been developed by comparing the loudness of sounds of all audible frequencies and intensities to an arbitrarily chosen reference tone. The loudness level, in phons, of the pure 1000 cycle reference tone is taken to be numerically equal to the intensity level, in decibels, above the adopted reference intensity of 10^{-16} watts per square centimeter. The dependence of the ear upon frequency and intensity for sounds of equal loudness level is shown in Figure 3.

It is evident that the ear responds better to some frequencies than to others. This means that tones of two unlike frequencies which are adjusted to the same loudness level may have entirely different intensities. The amount by which the intensity levels of sounds of any two frequencies must differ in order to appear equally loud is shown by these curves. Each curve represents a contour of equal loudness. They show that at low sound levels the ear is relatively insensitive to low frequencies, but at high sound levels it hears them almost as well as it does the high frequencies. They also show that the human ear has a limited frequency response range. These contours, called the Fletcher-Munson curves, have been determined by testing large numbers of individuals and are considered representative of the average human ear.

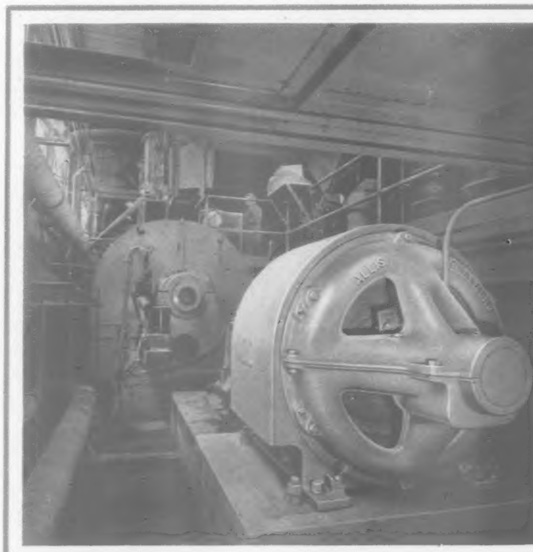
Having defined sound in its psychological and physiological aspects, we recognize that the engineer is most concerned with the physical phenomena which produces sound. This discussion on the terminology of acoustics and the characteristics of sound waves will be followed by Part II which will present instruments and procedures for analyzing sound and reducing noise.

How Varying Load Conditions

Influence Motor Selection

Motors can be safely overloaded when proper cooling time is provided. Useful data for such estimating is provided by the authors.

F. K. BRAINARD and FRASER JEFFREY
Electrical Department — Allis-Chalmers Mfg. Co.



BANBURY MIXERS, as this one driven by a 300 hp synchronous motor in a rubber plant, and steel rolling mills are typical of unsteady loads which make correct motor selection difficult.

CORRECT application of an electric motor to its driven machine is much more difficult when a load is of a highly intermittent nature than when it is steady. Such conditions are commonly encountered in steel rolling mills and certain processes in the rubber industry.

In considering power requirements for intermittent loading with peak conditions occurring at frequent intervals it is well to work with equivalent hp corresponding to rms (root mean square) values of kva rather than rms values of power directly. This is because the power factor and the efficiency of both synchronous and induction motors vary with the load, and the current or kva will not be proportional to the load. As shown later, rms values of power may be used if only approximate results are desired.

Fixed and variable losses

The sum of the values of stator copper loss plus stray loss in a synchronous motor, or the sum of stator copper loss plus stray loss plus rotor copper loss in an induction motor, is very nearly proportional to the square of the stator current. Also, the remaining losses are practically independent of stator current and of the load on the motor. For example, the core loss depends almost entirely upon line voltage and, since this voltage applied to a motor is ordinarily constant, the core loss is consequently practically constant.

Since the field current in a synchronous motor is ordinarily held constant, the excitation loss is also constant.

On the other hand, the rotor copper loss in an induction motor varies as the square of the rotor current and hence may be considered as varying roughly as the square of the stator current in those cases where the magnetizing current is small relative to the full load current.

Thus the total loss consists of two parts, one part being practically constant and the other varying very nearly as the square of the stator current. The general characteristics of a typical slip ring type induction motor is shown in Figure 1, a typical unity power factor synchronous motor with constant field excitation in Figure 2 and a typical 80 percent power factor synchronous motor with constant field excitation, by Figure 3.

The values given on these curves are shown merely for the purpose of illustration. They vary widely, depending on the size and speed of each individual motor. However, the values illustrated indicate the large variations from straight line characteristics in stator current or kva due to power factor and efficiency variations that occur both at low loads and at large overloads. Because of these wide variations in characteristics, it can readily be seen that the kva input is not directly proportional to the load, and therefore, when considering intermittent loading, this feature must be given careful consideration if accurate results are desired.

To determine the value of kva which will give the same average heating as the actual variable kva, a curve of kva can be plotted over the load cycle from the known characteristics of the motor, and then another curve of kva squared can also be plotted. The average of this latter curve can be determined in the usual way. The square root of this average, called the "root mean square," will be the value of kva to be considered in applying the proper motor, since it will produce the same average heating as the actual variable kva input.

This method of analyzing load curves can be further illustrated by considering the irregular load cycle shown in Figure 4.

For such an irregular load curve, the sharp slopes should be divided up into small portions of time and the resulting kva input will then be:

$$\text{rms kva} = .746\sqrt{\frac{\left(\frac{P_1}{\text{Cos}\ \phi_1\ \eta_1}\right)^2 t_1 + \left(\frac{P_2}{\text{Cos}\ \phi_2\ \eta_2}\right)^2 t_2 \ldots + \left(\frac{P_n}{\text{Cos}\ \phi_1\ \eta_n}\right)^2 t_n}{t_1 + t_2 + \ldots\ldots\ldots\ldots\ldots\ldots t_n}} \quad (1)$$

where P_1, P_2, etc. to P_n = load in horsepower during time intervals t_1, t_2, t_3, etc. (This value may be taken from the curve at the middle of the interval in question and is assumed constant during the interval.)

$\text{Cos}\ \phi_n$ = Power factor of motor at power load P_n.
$\text{Cos}\ \phi$ = Full load rated power factor of motor.
η_n = Efficiency of motor at power load P_n.
η = Full load efficiency of motor.
t = Unit of time.

The equivalent hp rating of a motor corresponding to the rms kva input as per equation (1), i.e., the hp rating of a motor which, if operated continuously at full load, would show the same average heating as it would if operated on the load cycle in question, will be:

$$\text{Equivalent hp} = \frac{\text{rms kva from equation (1)} \times \text{Cos}\ \phi \times \eta}{.746} \quad (2)$$

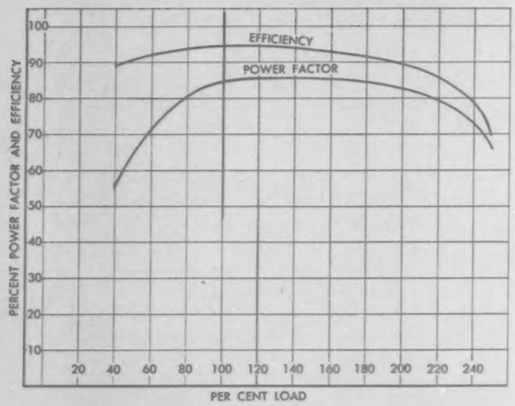
Substituting equation (1) in equation (2) we have:

$$\text{Equivalent hp} = \text{Cos}\ \phi \times n \sqrt{\frac{\left(\frac{P_1}{\text{Cos}\ \phi_1\ \eta_1}\right)^2 t_1 \ldots\ldots + \left(\frac{P_2}{\text{Cos}\ \phi_2\ \eta_2}\right)^2 t_2 + \left(\frac{P_n}{\text{Cos}\ \phi_n\ \eta_n}\right)^2 t_n}{t_1 + t_2 + \ldots\ldots\ldots\ldots\ldots\ldots t_n}} \quad (3)$$

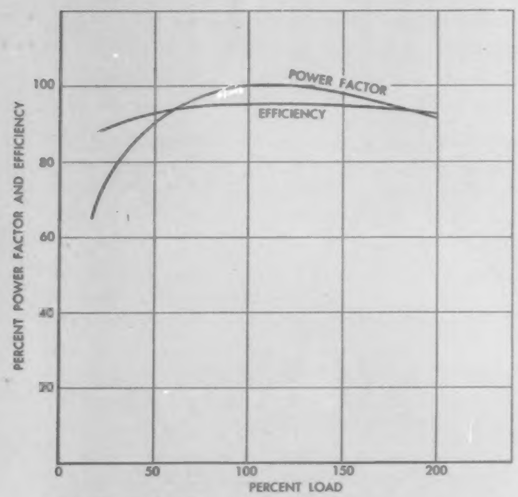
Where the slope of the load curve is abrupt, as in Figure 5, the time intervals, such as from t_2 to t_9, should be made rather small, whereas the intervals t_1, t_{10}, etc., can be made larger, as shown.

Motor application

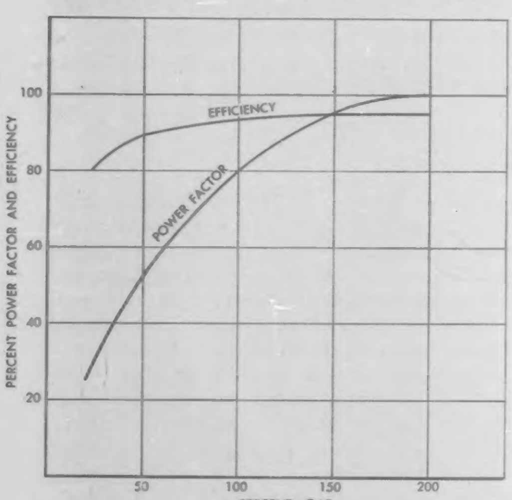
In the application of motors to violently varying loads, great care, however, must be exercised to see that certain parts having low thermal capacities such as soldered joints, cables, slip rings, brushes, etc., do not exceed the average temperature by excessive amounts at certain points in the load cycle. This is true where the peak loads are relatively high compared to the continuous rating of the motor and especially so if such loads are of relatively long duration. In other words, an apparently satisfactory value of rms kva represents "average" heating only and consideration must always be given to limit the heating and duration of the peak loads to values which will not produce excessive local or momentary heating. It is evident that an apparently safe value of rms kva might be obtained from a combination of high peak load of too long duration and an unusually long idling condition.



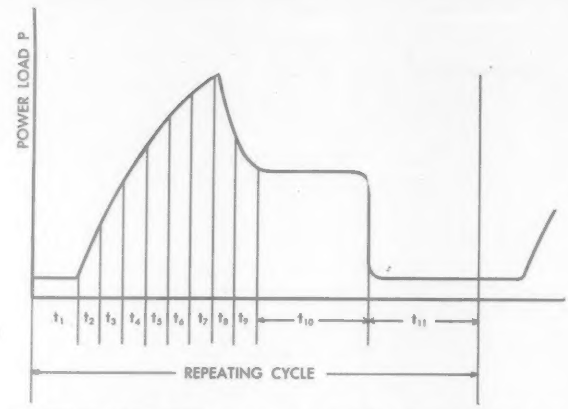
GENERAL CHARACTERISTICS of a typical slip ring induction motor are shown by these performance curves. **(FIGURE 1)**



CHARACTERISTICS of a unity pf synchronous motor with the excitation held constant at the full load value. **(FIGURE 2)**



PERFORMANCE CURVES are typical of an 80 percent power factor synchronous motor with full load excitation. **(FIG. 3)**



IRREGULAR LOAD CYCLE has sharp slopes divided into small time intervals to obtain equivalent hva with greater accuracy. **(FIG. 4)**

It is well to remember that the correct application of electric drives to any given load cannot always be judged from the temperature limits alone, but rather like a chain, from the weakest link in its structure. Such conditions might be due to limitations in mechanical parts, to the wear and tear on insulation caused by the expansion and contraction effects of the copper making up the coils, to the torque and current requirements as well as to commutation where d-c equipment is involved, etc.

It is also well to note that the pull out torque of a synchronous motor with constant excitation varies directly with the voltage while that of an induction motor varies as the square of the voltage. The pull out torque of a synchronous motor therefore should exceed the maximum expected load torque by a reasonable margin, say 15 to 20 percent or more to allow for a possible drop in line voltage, whereas the margin on maximum torque for an induction motor application should be 40 to 45 percent or more, for the same permissible limits of voltage variation. However, in the selection of any motor, conditions may vary greatly because of different operational cycles used in different manufacturing plants or with different materials which might also considerably affect the power and torque conditions required even when using the same driven machine.

Motor characteristics affect ratings

Some simple examples will show the different results that might be obtained by different methods of computation, different power factor ratings of synchronous motors and the use of induction motors instead of synchronous motors.

Consider a synchronous motor that is rated 600 hp, 100 percent pf and applied to a load of five minutes at 300 hp, then 30 seconds at 1200 hp, repeating the same cycle continuously without any idling period between such cycles. This load cycle shown in Figure 5. The field current is assumed to remain constant.

As a first approximation, assume that the current varies directly with the load. The rms hp rating of the motor can then be obtained by determining the rms value of the load cycle directly and

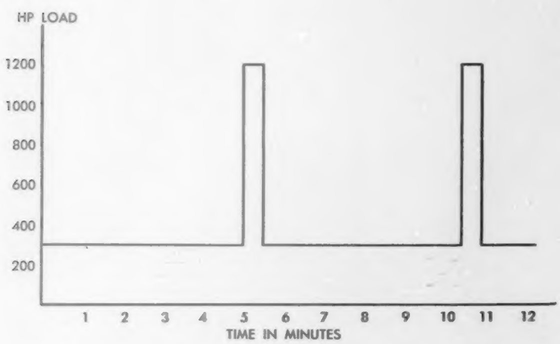
$$\text{rms hp} = \sqrt{\frac{(300)^2 \times 5 + (1200)^2 \times \frac{1}{2}}{5\frac{1}{2}}} = 462 \text{ hp}$$

Correct consideration of this problem, however, should also take into account variations in power factor and efficiency due to the high fluctuating loads.

If the full load efficiency of this 600 hp, 100 per cent pf motor is 95 percent, the half load efficiency and pf 92 percent and 90 percent respectively and the 200 percent load efficiency and pf 93 percent and 91 percent respectively (see Figure 2), the equivalent hp will be:

$$1.0 \times .95 \sqrt{\frac{\left(\frac{300}{.90 \times .92}\right)^2 \times 5 + \left(\frac{1200}{.91 \times .93}\right)^2 \times ½}{5½}}$$
$$= 522 \text{ hp}$$

From a heating standpoint it will be noted that there is a variation between 462 hp, without consideration of power factor or efficiency, and 522 hp when these factors are considered. While an equivalent hp value of 522 hp might indicate a satisfactory motor size insofar as average winding temperature is concerned, serious consideration must be given not only to starting torque, pull in torque, and maximum torque limitations but also to the length of time of the peak load conditions where the temperature rise of certain parts of the machine might be sufficient to cause failure of those parts which ordinarily might not be considered at all.



LOAD CYCLE to which a 600 horsepower synchronous motor is applied 300 hp for 15 minutes and 1200 hp for 30 seconds. **(FIGURE 5)**

For further comparison consider a synchronous motor rated 600 hp, 80 percent pf applied to the same load cycle as the 600 hp, 100 percent pf synchronous motor, namely 5 minutes at 300 hp, then 30 seconds at 1,200 hp, repeating the same cycle continuously without any idling period.

Assume that this motor has a full load efficiency at 80 percent pf of 93.5 percent, and at 300 hp load a power factor of 52 percent leading and an efficiency of 89 percent, and at 1,200 hp load a power factor of 100 percent and an efficiency of 95 percent (see Figure 3). The equivalent hp would then be:

$$.80 \times .935 \sqrt{\frac{\left(\frac{300}{.52 \times .89}\right)^2 \times 5 + \left(\frac{1200}{1.00 \times .95}\right)^2 \times ½}{5½}}$$
$$= 544 \text{ hp}$$

If a slip ring type induction motor rated 600 hp were applied to the same intermittent duty cycle as the 80 and 100 percent of synchronous motors, and if this machine at 300 hp load had a power factor of 65 percent and an efficiency of 91 percent and at 1,200 hp load a power factor of 83 percent and efficiency of 89 percent, then, if the full load efficiency and power factor of this motor were 94.5 percent and 85 percent respectively (see Figure 1), the equivalent hp would be:

$$.85 \times .945 \sqrt{\frac{\left(\frac{300}{.65 \times .91}\right)^2 \times 5 + \left(\frac{1200}{.83 \times .89}\right)^2 \times ½}{5½}}$$
$$= 554 \text{ hp}$$

These comparisons show that the ratings of a-c motors required for intermittent loadings will depend on the kind of motor used, i.e., whether it is a unity of 80 percent pf synchronous motor or an induction motor, and to a lesser degree on the characteristics of the particular motor under consideration.

Summarizing the above we have the following comparisons:

COMPARISON OF MOTORS

Motor		Full load pf	Full load eff.	Calculated equivalent hp
600 hp	100% pf Synchronous	100%	95%	522
600 hp	80% pf Synchronous	80%	93.5	544
600 hp	Induction	85%	94.5	554

The chart indicates from a current heating standpoint, disregarding starting torque and maximum torque and effect of heating of winding parts for the duration of the peak loads, that

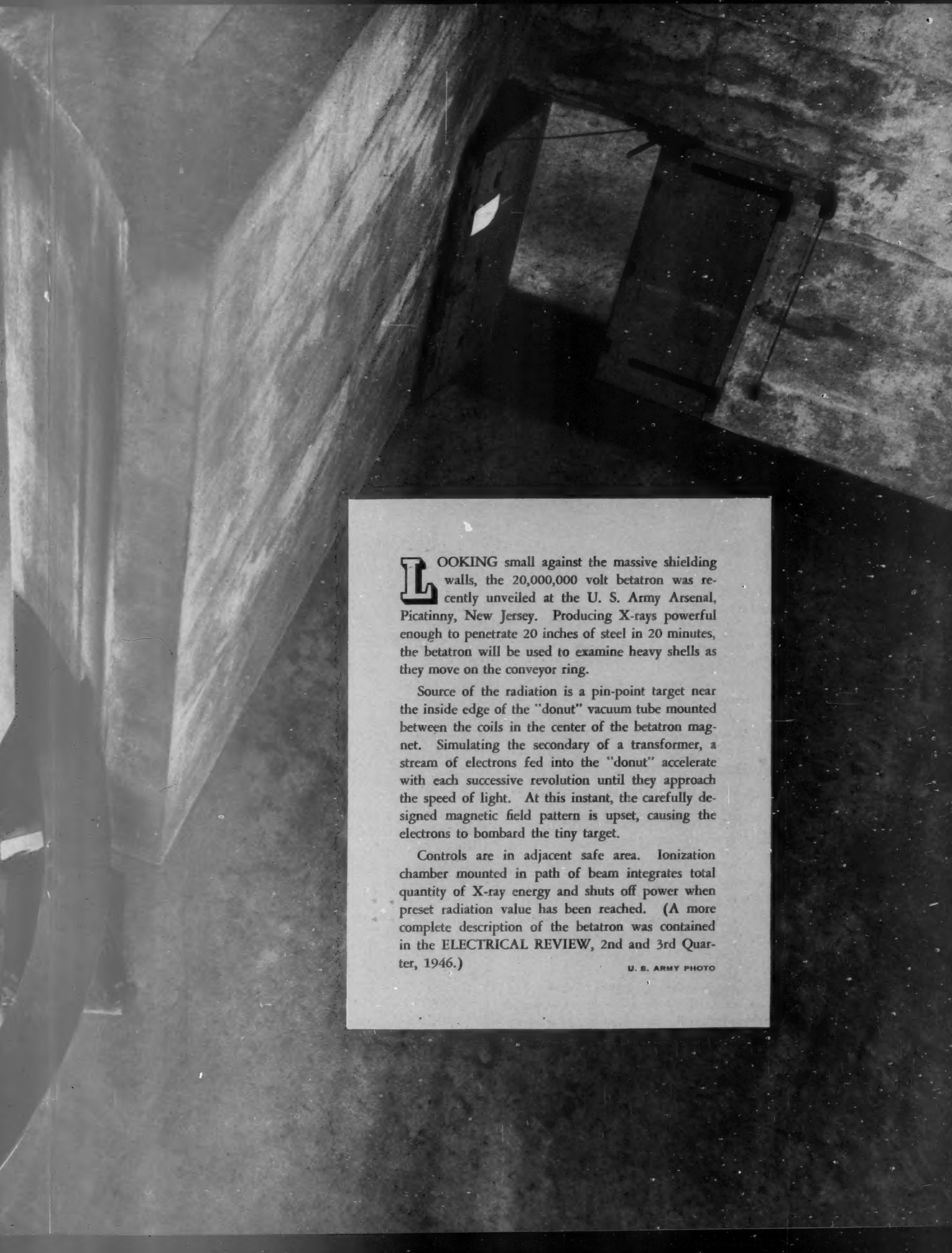
1. A 522 hp 100 percent pf synchronous motor might appear satisfactory.
2. A 544 hp 80 percent pf synchronous motor might appear satisfactory.
3. A 554 hp induction motor might appear satisfactory.

Under ordinary conditions it would seem best to avoid loading electrical equipment to the point where such would impose peak load requirements that are very close to the maximum torque capacity of the motor. Under such conditions there would be very little leeway or factor of safety between the actual torque demand and the breakdown torque of the motor. It is under such peak load conditions where, if values required approach the maximum torque capacity of the motor, dangerous heating might develop in unexpected places even though the winding temperatures of the motor itself may appear normal.

Short time ratings of equipment can be predicted if something is known about the temperature curves of the electrical machine itself. While the temperatures derived under such a method are, in general, the temperatures of the windings, such temperatures can be calculated and will be in fair agreement with actual tests.

Thus there are three factors in a rough approximation of a highly intermittent load cycle. The first might be obtained by neglecting the power factor and efficiency and taking the rms values of horsepower only. Ultimately these values should be changed as shown above to values which consider both the power factors and efficiencies of the motor to be used at the various loads.

And then, finally, care must be exercised to make certain that the starting, pull in, and maximum pull out torques of the motor under the proposed operating conditions will be suitable for the load to be handled.



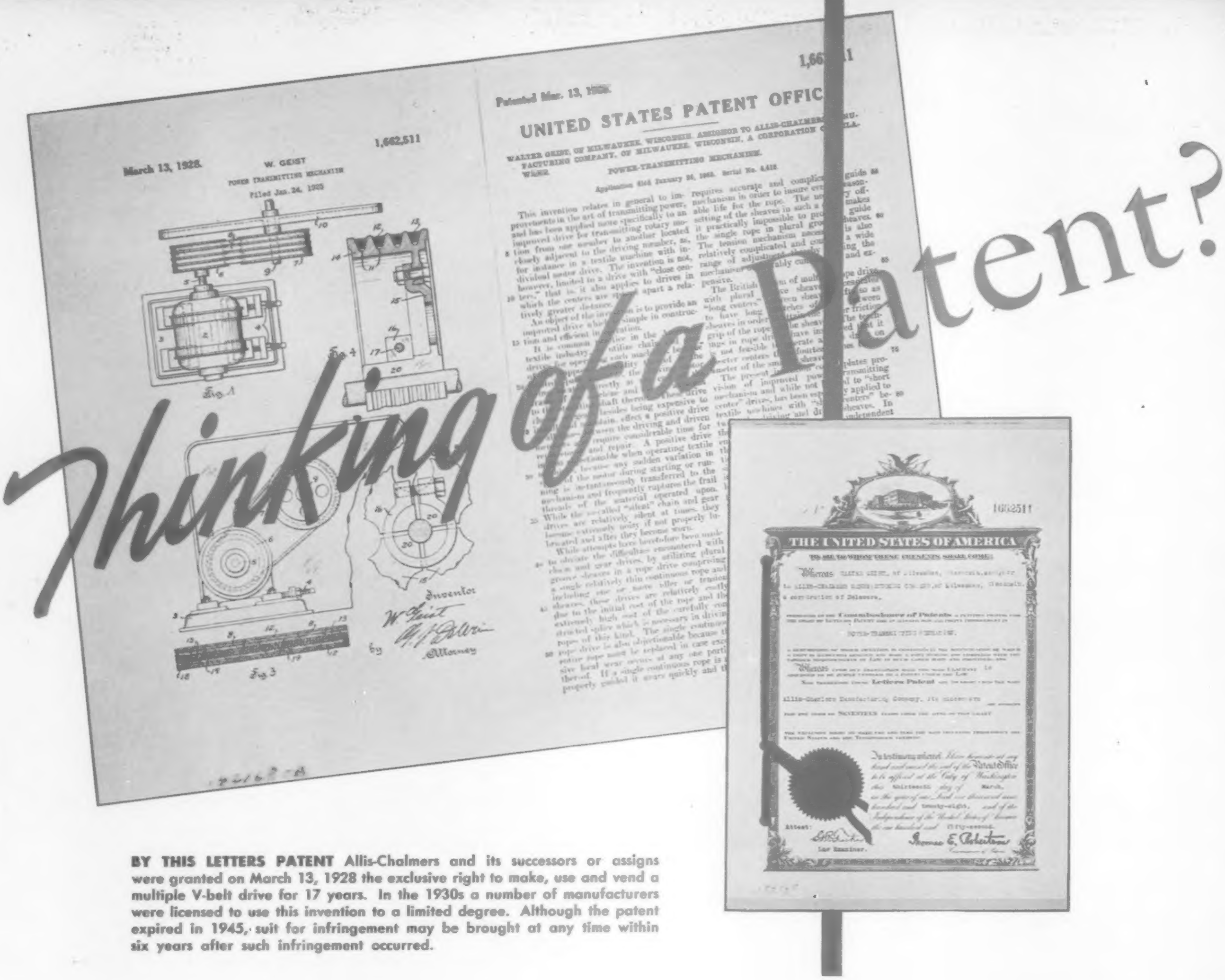
LOOKING small against the massive shielding walls, the 20,000,000 volt betatron was recently unveiled at the U. S. Army Arsenal, Picatinny, New Jersey. Producing X-rays powerful enough to penetrate 20 inches of steel in 20 minutes, the betatron will be used to examine heavy shells as they move on the conveyor ring.

Source of the radiation is a pin-point target near the inside edge of the "donut" vacuum tube mounted between the coils in the center of the betatron magnet. Simulating the secondary of a transformer, a stream of electrons fed into the "donut" accelerate with each successive revolution until they approach the speed of light. At this instant, the carefully designed magnetic field pattern is upset, causing the electrons to bombard the tiny target.

Controls are in adjacent safe area. Ionization chamber mounted in path of beam integrates total quantity of X-ray energy and shuts off power when preset radiation value has been reached. (A more complete description of the betatron was contained in the ELECTRICAL REVIEW, 2nd and 3rd Quarter, 1946.)

U. S. ARMY PHOTO

Thinking of a Patent?



BY THIS LETTERS PATENT Allis-Chalmers and its successors or assigns were granted on March 13, 1928 the exclusive right to make, use and vend a multiple V-belt drive for 17 years. In the 1930s a number of manufacturers were licensed to use this invention to a limited degree. Although the patent expired in 1945, suit for infringement may be brought at any time within six years after such infringement occurred.

★ ★ ★

Infringement and licensing of inventions, as well as original patent grants, should be legal terms understood by every engineer.

★ ★ ★

W. S. GATES
Patent Dept. — Allis-Chalmers Mfg. Co.

"SAY, you've got something good there, Jones. Just get a patent on that little shaft coupling and you're sure to make a fortune." Such well-intended advice to a man of ideas may be heard most any day, but it is too often based on some common misunderstandings concerning patents.

The first erroneous thought that often lies behind such enthusiastic advice is the idea that every new product or process, which differs in the slightest degree from what is generally available in the market, or used in industry, is patentable. The second is that the grant of a patent gives the patentee the right to proceed with the production of his product or the use of his process, without regard to the patents of others. The third is that once a patent has been obtained it throttles competition, prevents copying and brings a free flow of bounty to the inventor.

Our Constitution gives Congress the power "to promote the progress of science and the useful arts, by securing for limited times to authors and inventors an exclusive right to their respective writings and discoveries." A patentable invention under the Constitution is, of course, a "discovery" of an "inventor." Going back into the history behind the Constitutional provision for the patent system, we find, as did Queen Elizabeth of England in about 1601, that in order that the patent grant may not be obnoxious to the public, it must not take away rights which the public had before the patent was granted.

Law protects creative inventors

The body of law which has grown up under the provision of the Constitution, therefore, sanctions the granting of patents only to original, or creative inventors. The grant is given only to those who disclose to the public something with relation to

which it has not formerly possessed any rights. Since the patent grant is in the nature of a contract by which, in return for the disclosure of something new and useful and previously not available to the public, the government grants a limited exclusive right, the grant cannot be valid if the subject matter previously has been made available to the public. It follows that advances which amount to no more than normally expected or routine improvements of products or processes through application of knowledge already available to the public are not patentable.

"But," Jones says, "that coupling of mine can be useful in hundreds of places. I didn't get my idea from anyone else. And furthermore, there is nothing like it on the market now, and they would sell like hotcakes. Surely, that gives me a right to a patent."

Nevertheless, Jones may not have a right to a patent, for it may be that another man a long time ago produced substantially the same thing, used it in public, and described it in some obscure publication. Perhaps the reason that the same or a similar product is not on the market today is that the earlier man did not have a ready market for his product, or could find no capital to back production. Maybe the product was too costly for public acceptance. Whatever the reason may be, if all the essential features of the invention were available to the public before Jones thought of it, he cannot get a valid patent even though the disclosure be buried away in some half-forgotten tome.

Only improvement is protected

"But," Jones says, when confronted with an ancient patent (or some other early publication), "this patent describes only the bare essentials of a flexible coupling. I've made an important improvement over what is shown in this patent. My coupling has flange parts secured to two shaft ends, and a resilient coupling member, like the one shown in the patent; but my resilient coupling member is different in form and engages the flange parts in a different way. Can't I get a patent on such an improved coupling?"

Yes, Jones may indeed be entitled to a patent covering at least his particular novel form of resilient coupling member and its novel relation to the flange parts, provided the advance he has made can be said to involve more than the ordinary skill of his calling. In this case, Jones will be granted a patent giving him the exclusive right to make, use, and vend couplings involving his particular form and arrangement of resilient coupling members and flange parts.

Jones' Letters Patent, however, can be used only to exclude others from making, using, or vending his particular form of improvement. His patent cannot prevent competitors from using any coupling structure previously made available to the public, even though never before actually manufactured or generally known. And it cannot prevent the manufacture, sale, or use of other improved couplings involving other forms and relationships of parts, unless such forms and relationships are mere equivalents of Jones' improvement.

Thus, a patent is an exclusive right only to what has previously been unknown and unavailable to the public and might not have become known or available but for the patentee's particular ingenuity, inventive effort and disclosure to the public.

"Exclusive" is key to grant

The word "exclusive" is the key word in the fundamental patent provision of the Constitution and in the patent grant. The patent grant does not give the inventor a right to sell or use his invention. The patent grant merely makes *exclusive* this right, which the inventor would have without the patent grant. That is, the patent grant gives the patentee the right to *exclude others* for a limited time from the practice of his patentable invention. By the same token, the patentee may himself be excluded from the practice of the patented inventions of others.

"Does this mean that I can be prevented from practicing my own invention?" Jones asks.

Let's assume that not Jones, but another person called Smith, has an earlier unexpired patent broadly covering all couplings involving two flange parts and a resilient coupling member, and that no useful coupling involving Jones' patented improvement can be devised which does not involve the use of Smith's earlier patented invention.

Smith learns of Jones' invention and, conscious of the exclusive nature of his patent grant, says to him: "Jones, you can't make couplings according to your invention. I have a patent which covers couplings like yours."

"Well!" says Jones, "I have a patent here that gives *me* the exclusive right to make, use, and vend my coupling."

"That's right," says Smith, "you have that right if you can do it without incidentally using *my* invention. But, as you see, *my* patent gives me the exclusive right to *my* invention; and I can't see how your coupling can be made without using my invention."

Thus the broader patent grant to Smith can be enforced to exclude Jones from the practice of the Jones invention during the life of the Smith patent grant, provided the Jones invention cannot be practiced without use of the patented Smith invention. Therefore, even though Jones is entitled to a patent, the patent law does not give him any right to proceed with the practice of his invention without regard to the patent rights of others. In fact, if Jones cannot make, use, and sell his own invention without infringing on the exclusive rights of others, he may actually be prevented from commercializing his invention, or reaping any reward whatever for his ingenuity, so long as such other exclusive rights exist.

Of course, while Smith has a broad patent and can dominate the field in his particular class of coupling, he may find that the Jones improvement, which he cannot use without license, would greatly reduce his costs of production, increase the sales appeal of his coupling, or in some other way promote an increased return from exploitation of the Smith patent coupling. If so, Smith may feel he can't get along without Jones' improvement and he may be willing to pay royalty for the right to use Jones' improvement or purchase the Jones patent. Jones may, in this way, be rewarded in an amount commensurate with the real value of his improvement, which is, in the last analysis, a share in the profits earned through use of his improvement which might not have been earned without it.

Litigation excludes others

The making of a patentable invention does not in some mysterious way directly exclude others from its use. During a frequently long period between the making of an invention and the granting of a patent covering the invention, the inventor gets no protection from the patent law at all. And if the inventor discloses his invention to others or publicly uses it, or commercially produces it during this period, others may copy his device or create it independently and sell it openly.

About the only deterrent to their doing this, if they know of Jones' invention and his intent to patent it, is an apprehension that the capital investment in production tools or plant may be partly lost if a patent issued to Jones is broad enough and strong enough to exclude the copiest or infringer or his customers from further practice of the invention patented. There is actually only one way in which the patent can be enforced to exclude others and that is through actual litigation, or the threat of it.

Actual litigation under the *patent* law cannot be started until after the grant of the patent, and cannot directly penalize practice of the invention by others before the date of issue of the patent. There is, of course, a fear on the part of him who consciously makes and sells the invention of another before patenting, that enforcement of the patent against his customers after it issues, to prevent such customers from further use of the invention, may result in loss to the seller. Such loss may come about through the operation of the provisions of the contract of sale which may involve a warranty as to the right to continued use of the equipment sold. There is, however, no police force to guard the rights of patentees. Patentees must themselves detect violation of their patent rights, and seek the aid of the courts to enforce them.

Patent system promotes progress

The patent system was not intended to afford protection to private parties against the copying by others of new products which involve only improvements normally to be expected in the orderly course of product development. The primary purpose of the patent system is to *promote* the progress of science and the useful arts, not to secure the benefits of monopoly to private parties. This purpose is achieved by acquainting the public with advances requiring more than ordinary ingenuity and by keeping alive the disclosures others have made in the past.

The reward which the inventor hopes for, and which furnishes him with an incentive to invent and disclose his inventions, is not directly provided for by the patent law, which merely establishes conditions favorable to exclusive exploitation of an invention by its owner for a limited period of time. The reward, if any, must be earned by commercial exploitation of the invention, or obtained by sale of rights to someone who believes he can make profits by virtue of possession of such rights.

With a little better understanding of the complexities of the patent law, the advice "Get a patent and you'll make a fortune" might more helpfully be — "Jones, I never saw anything like your coupling before. It might be worth your while to have an expert investigate the patent situation."

New Products

Betatron Ready for Industrial Use

The first commercial betatron, a two-million volt automatically controlled X-ray generator, is a result of experience and design improvements gained in building several units for wartime research.

This compact yet powerful unit uses a stream of electrons oscillating inside an evacuated donut-shaped tube as the secondary of a transformer. By spinning around many hundred thousand times the electron stream reaches an energy value of 20 million volts before being deflected to strike the top of a very small target. The extremely penetrating X-rays permit production radiographs to be taken through 18 inches of steel in five minutes. The largest X-ray equipment now in use takes several days for such a radiograph.

The unit is designed to operate from any three-phase standard voltage source and requires about 25 kva.

New Pedrifugal Line Meets Need for Flexible, Moderate-Capacity Pump

Expressly designed for use with Texrope V-Belt Drives which give an infinite range of capacities regulated by the sheave size and power supplied, a new line of Pedrifugal pumps meets the demand for a sturdy, reliable pump of moderate capacity.

All pumps are fitted with runners of maximum diameter, and variations in capacity are provided by sheaves of larger or smaller diameters.

Small and compactly designed, all sizes have essentially the same dimensions. This compactness, plus the fact that the pumps operate in any position, makes the unit well suited to designers of such equipment as commercial washers and cleaners, machine tools, air conditioners, heat exchangers and cooling towers.

The new line of cast iron, bronze-fitted pedestal type Pedrifugal pumps consists of three principal sizes: 1 inch by 1 inch, 2 by 2, and 3 by 3 with capacities from 10 to 500 gallons per minute at heads from 10 to 100 feet. Power requirements range from ¼ to 15 horsepower.

MORE FACTS about these new products are available on request. Write the Allis-Chalmers ELECTRICAL REVIEW, Allis-Chalmers, Milwaukee 1, Wisconsin.

What is a "Bigger" Transformer?

Size, weight and characteristics of a transformer can be estimated with surprising speed, accuracy.

W. C. SEALEY
Transformer Section,
Allis-Chalmers Mfg. Co.

WHEN a transformer becomes too small for its application, the user may decide he wants one twice as big.

"But," says the designer, "just what do you mean by twice as big?"

"Why anyone can see," replies the user, "that this one is so large, and one twice its size is twice as big."

But let's see if the problem is that simple! Transformer size refers to many things — physical dimensions, weight, kva rating and other performance characteristics. These characteristics describe what the transformer will do, and the most important of them are kva rating, high voltage, low voltage, time the load can be carried, whether load is continuous or short time, impedance, exciting current, no load loss, copper or load loss, and whether the unit will be used indoors or outdoors.

To determine the correct size of a transformer for a particular application, the user specifies the performance characteristics which are most important to him. All other characteristics of mechanical and electrical construction are left to the experience of the designer.

The first step in deciding how much and in what respects to increase the size of a transformer is to find out what is wrong with the unit in current use. This is determined by checking the primary voltage against the power supply, the secondary voltage, the impedance, the exciting current, etc. We shall assume that the current rating of the high voltage winding is correct, but that the high voltage should be 20 percent greater.

By using a simple system of relations in cases where construction is similar, it is possible to estimate cost of this larger transformer and the effect of 20 percent greater high voltage on other performance characteristics.

This system works for large power units as well as small ones.

Fundamental relations determine size

Since a transformer is a static electrical device which electromagnetically transforms alternating current energy from one circuit to another, it is, basically, a mechanical structure designed for specified electrical characteristics. As such, a wide variety of mechanical arrangements are used to secure the required electrical characteristics, with the type of construction determined by experience in designing and comparing a large number of transformers of different types.

After the best proportions have been determined for a given rating of transformer, the performance and size of similar transformers of different ratings may be estimated by using fundamental relations which can be derived. The design of a transformer for a given application may thus be considered to be a problem involving a large number of requirements and a large number of variables.

Although the requirements may be originally stated in more general terms, they can be analyzed and are commonly expressed in terms of kva rating, voltage, frequency, temperature rise for continuous operation, losses, impedance, voltage regulation, test voltages and suitability for indoor or outdoor operation. Generally implied are such factors as long life, dependability, minimum weight and size consistent with meeting the specifications.

A given set of requirements can be met with an infinite number of designs, having different core and coil arrangements and different quantities of the copper, iron, insulation, etc., from which the transformer is constructed. The requirements may also vary from time to time and between applications. There are improvements in materials and in the techniques of using materials. Consequently, for a given rating the best design will be different at different times and for different applications.

To determine whether a given design is the best design to meet given specifications, the effect on the size of a change in each of the significant variables should be analyzed. For example, if the use of either a larger core section or a smaller core section increases the total cost, it may be assumed that the best core section for that design has been selected. Similar checks may be made for other factors which are under the designer's control. If none of these produce an overall improvement, the design in question is probably the best design for the type of construction selected.

The relations which will be derived will be found useful in making such designs, since approximate values of proportions can be estimated for a given size transformer. The derived methods may also be used as an alternative method of estimating performance if the kva ratings are close together, and using, as a basis for estimating, the transformer which has been designed.

Three assumptions are necessary

In order to simplify the derivation of the relations, transformers which are similar in construction and proportions are

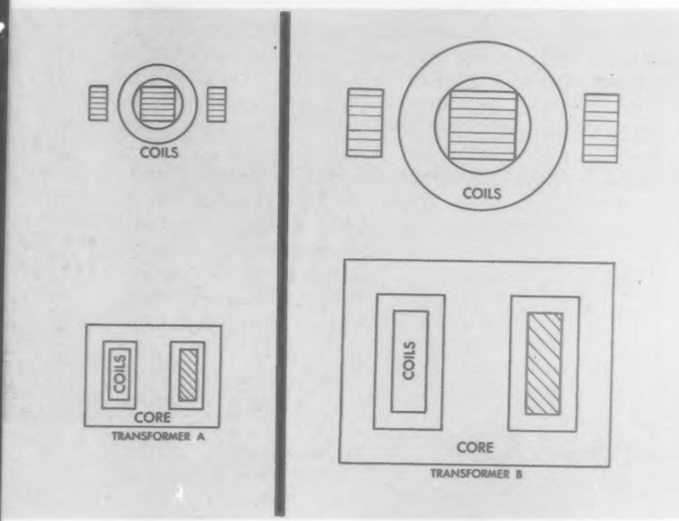
assumed. The following are convenient assumptions:

Constant physical proportions.

Constant current density and percent eddy loss in the copper.

Constant flux density in the iron.

Because in actual practical designs these factors are only approximately constant, the derived relations are approximate.



PROPORTIONS AND RELATIONS are shown by transformers a and b, above. Unit b at the right has exactly the same proportions as transformer a, but is a twice-as-large "to scale" replica. (FIGURE 1)

Kva $= kL^4$

Weight $= k\ kva^{3/4} = kL^3$

Length $= k\ kva^{1/4} = kL$

Width $= k\ kva^{1/4} = kL$

Height $= k\ kva^{1/4} = kL$

Total watts loss $= k\ kva^{3/4} = kL^3$

No load loss $= k\ kva^{3/4} = kL^3$

Exciting volt amperes $= k\ kva^{3/4} = kL^3$

Exciting current in amperes for the same voltage $= k\ kva^{3/4} = kL^3$

Percent total loss $= k\ kva^{1/4} = k/L$

Percent no load loss $= k\ kva^{1/4} = k/L$

Product of no load loss and copper loss $= k\ kva^{1.5} = kL^6$

Product of % no load loss and % copper loss $= K\ Kva^{-.5} = K/L^2$

Percent exciting current $= k\ kva^{-1/4} = k/L$

Percent resistance $= k\ kva^{-1/4} = k/L$

Percent reactance $= k\ kva^{1/4} = k/L$

Volts per turn $= k\ kva^{1/2} = kL^2$

A plot of these relations is shown in Figure 3.

However, if the difference in rating is not too great, the relations are sufficiently accurate for estimating purposes.

Transformers a and b in Figure 1 illustrate proportions and relations. Transformer b has exactly the same proportions as transformer a, but is a "to scale" replica, being twice as long, twice as wide, and twice as high. Each transformer has the same number of turns. Since the cross section dimensions of the copper conductor of transformer b are twice those of transformer a, the area of the conductor and the corresponding current rating is four times that of transformer a. If the length of the transformer is represented by L, the cross section area of the conductor and its current rating is equal to kL^2. We shall use k as a quantity which has a different value in each equation. The value will vary even in one particular equation, but is reasonably constant over limited ranges.

An examination of the two figures will show that the cross section area of the core of transformer b is four times that of transformer a. The cross section area of the core is proportional to L^2; core area $= kL^2$. Since the flux density in the core is constant, the voltage across each turn of the transformer (volts per turn) $= kL^2$. Since the number of turns is the same for both transformers, the total voltage $= kL^2$.

$$\text{The kva rating of a transformer} = \frac{\text{voltage} \times \text{current.}}{1000}$$

Since the voltage is equal to kL^2, and the current is equal to kL^2, the kva rating is equal to kL^4. The cubic inches in each part of the transformer is equal to kL^3. The weight of each part, and the total weight is equal to kL^3.

Since the flux density in the core is constant, the watts loss in each pound of core iron is constant, and the core loss (no load loss) is proportional to the core weight. That is, the core loss $= kL^3$. Similarly, the exciting volt amperes required for each pound of core iron is constant, and the exciting volt amperes are proportional to the core weight. That is, the exciting volt amperes $= kL^3$.

If the current density in the copper and the percent eddy current losses are constant, each pound of copper will have the same watts copper loss in it, and the copper loss will be proportional to the weight. That is, copper loss $= kL^3$. Since both the core loss and the copper loss are proportional to the weight, the total loss is also proportional to the weight; total loss $= kL^3$. The product of the core and copper losses $= kL^6$.

Equations used to get relations

The equations obtained for the various relations may be solved simultaneously to obtain the relations between the various quantities and the kva by solving the relation kva $= kL^4$ for L and substituting in the equations for the other relations. $L = kva^{1/4} / k^{1/4}$. In addition, relations between other factors may be derived in the same manner.

One practical modification of these relations applies to the percent reactance which is proportional to the $kva^{1/2}$, when the insulation is increased to keep the space factor constant as the kva is increased. When the insulation class is maintained constant, the reactance naturally increases more slowly than this. In actual practice, because of service requirements,

the percent reactance is held practically constant over a wide range in kva rating.

The relations in Figure 2 may be used for estimating purposes as follows: Assume the following data applies to a 10,000 kva transformer, and that it is desired to know the approximate values for a 12,500 kva transformer:

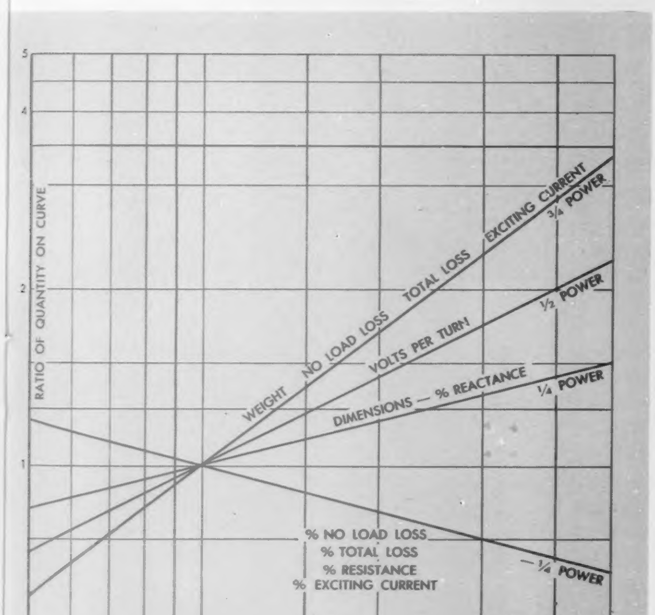
Table I

Weight	96,000 lbs.
No Load Loss	25,000 watts
Copper Loss	75,000 watts
Exciting Current	3%
Floor Space	Length 168 inches Width 100 inches

The ratio of the kva's is 1.25. The factors from Figure 3 for their quantities is 1.18 for all, except the floor space where the factor is 1.06 and the percent exciting current where the factor is .95. Multiply each of the values in Table I by the proper factor results in Table II, showing the approximate values of these quantities for a 12,500 kva transformer.

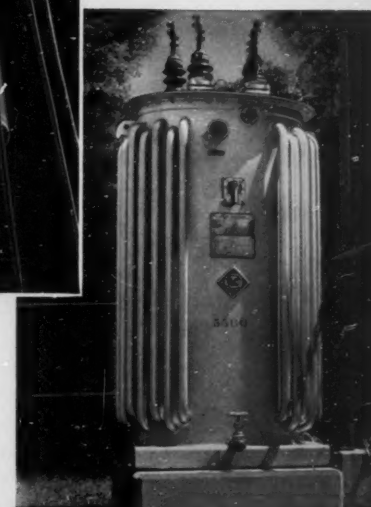
Table II

Weight	113,000 lbs.
No Load Loss	30,000 watts
Copper Loss	88,000 watts
Exciting Current	2.9%
Floor Space	Length 178 inches Width 106 inches

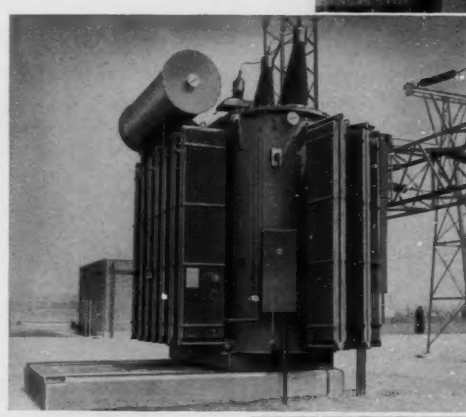


TRANSFORMER kva-characteristic ratio curves provide easy method of estimating sizes, weights, and losses in various size units. From these curves other variables can be determined. **(FIGURE 2)**

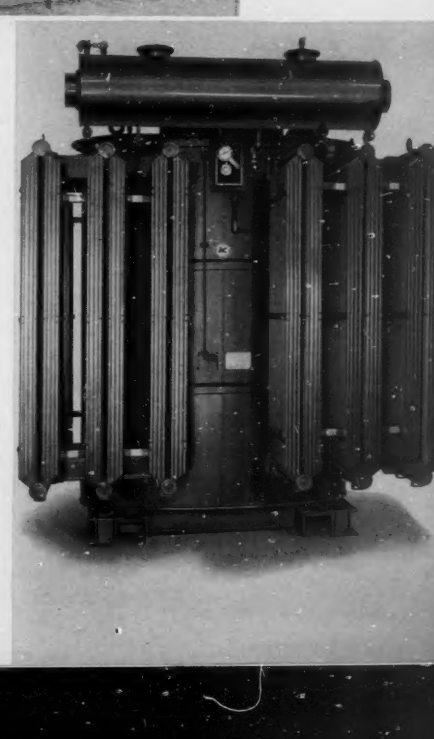
PLAIN TANK provides sufficient radiation surface for a small transformer. **(FIGURE 3a)**



ADDING TUBES obtains sufficient radiation surface for slightly larger transformers. **(FIGURE 3b)**



RADIATORS are used for still larger units, since adding enough tubes for adequate radiation surface interferes with painting. **(FIGURE 3c)**



VERY LARGE transformers are built with radiators banked on headers because there is inadequate space around the tank periphery for standard radiators. **(FIGURE 3d)**

Variations of assumptions

In all probability the 12,500 kva transformer, when it is actually designed, will not have exactly the values given in Table II for any of the quantities, but the values will not differ greatly. The reason for this variation of the actual from the estimated values is that the assumptions which were made in deriving the relations are not completely accurate. The assumptions made do form a good basis for estimating, but variations from these assumptions must be made for the best design. These variations limit the range over which the relations can be applied and also affect the accuracy of the relations.

The assumption which causes the greatest variation is that of constant physical proportions. This means that a transformer would contain a constant proportion of the total space as insulation space. Thus the clearances to ground for larger transformers will be greater than the clearances for smaller transformers. Actually, for a given voltage class the clearances are nearly the same. The error introduced by this factor is less for large transformers and for low voltage transformers than for small transformers or high voltage transformers where the space occupied by the major insulation is a larger proportion of the total space.

The losses of a transformer vary as the cube of the linear dimensions (for example, the length), while the exposed surface for heat dissipation varies as a square of the linear dimensions. One transformer which has its dimensions equal to twice the dimensions of another transformer will have eight times the loss, but only four times the radiation surface. Thus the necessity for adding radiation surface such as tubes, radiators, etc., for large transformers while small transformers can be provided with sufficient radiation surface by a plain tank without radiators. See Figures 3a, b, c, d.

A comparison of these tanks show that the assumption of constant physical proportions has been violated and illustrates that the relations hold reasonably well between transformers with a given type of construction, but will not hold when extended from the plain tank construction to the construction with banked radiators.

Typical of other changes which may be made between different transformers of different ratings is a change in type of construction. The assumption of constant cost per pound of material and constant cost per pound of labor is only an approximation because small, round wire for small coils is relatively more expensive than large strap wire, etc. Transformers, as designed, may have different proportions of material. Copper is a more expensive material than core steel, and the iron used for the tank wall is much less expensive than the high silicon steel which is used for the transformer core. These instances are but a few of the variations from the assumption of constant physical proportion which occur.

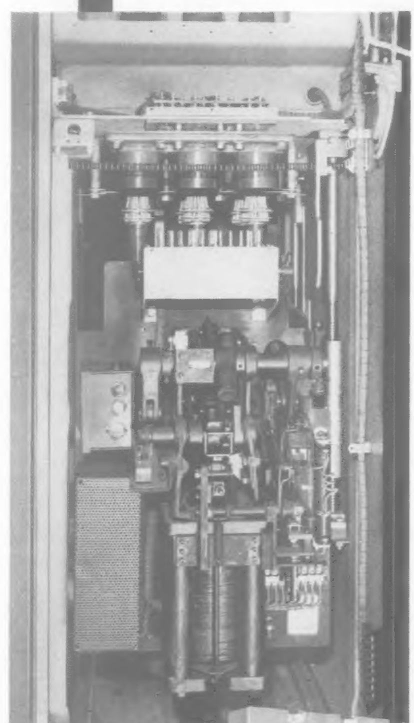
The assumptions of constant current density in the copper and constant flux density in the iron can be realized if one desires without particular difficulty. However, larger transformers do have a higher percent eddy current loss than small transformers unless special means, such as transposition, are used to limit this effect.

By using these relations for cases where the construction is similar, while the relations are not precise, they do afford a ready and useful method of making comparisons and in checking designs of similar transformers.

R. B. STEINER and ROBERT LOEWE
Switchgear Section — Allis-Chalmers Mfg. Co.

Breakers have come a long way since the early knife switch. A few of the many ways of tripping breaker contacts are outlined.

Me



ELECTRICALLY operated oil circuit breaker element shows assembly of rectifier, aging resistor and x and y relays. (**FIGURE 1**)

TO ENSURE safe operation, air blast circuit breakers must be electropneumatically opened and closed. (**FIGURE 2**)

Methods of Closing and Tripping Circuit Breakers

MANY misconceptions exist about methods of closing and tripping of circuit breakers and these wrong ideas become even more confused when the thinking broadens from just oil circuit breakers to include air circuit breakers, such as the low voltage magnetic types, the magnetic air breaker and the air blast breaker. Fundamentally the problems involved in closing and tripping are the same for all types of breakers.

The working of a circuit breaker, regardless of types, employs two basic operations, closing and tripping. These operations may be automatic or non-automatic and, in the latter case, done either manually or by electric and/or pneumatic power.

Since a breaker must be closed before it can open, the fundamental considerations in determining the method of closing are these:

1. Size of the breaker and, as a result, the manual effort required to close.
2. Distance between operator and breaker.
3. Automatic operation requirements.

Wherever closing the breaker requires great effort, it is assumed that the breaker should be closed by power. Power operation is also required when the breaker must be operated from a distance or by means of pilot devices such as float switches, under voltage relays, pressure switches, time switches, etc.

When the breaker is small or operation is infrequent, or where first cost is a major consideration and where no automatic closing is required, manual closing may be safely recommended.

Although the problem is the same regardless of type of breaker, the methods of solution differ. As a general rule, magnetic breakers should *always* be electrically closed except during emergencies and for making certain tests. Air blast breakers must *never* be closed manually and should *always* be power operated. The last is a "must" because only power operation makes the complete set of safety interlocks operative, insuring that the breaker having been closed can be safely opened. For safe operation a sufficient volume of air at the proper high pressure must be available, otherwise the interrupting element will fail to interrupt with damage to the breaker and, in addition, possible property damage.

Breaker operators may be divided into three general types:

1. Manual
2. Electrical (Solenoid or Motor driven)
3. Pneumatic

Manual operation is cheapest

Manual closing is, in general, the simplest, cheapest, and where properly applied, the most reliable. Circuit breakers are usually built so that some sort of mechanical latch holds them closed until the breaker is to be opened. This is true except for the air blast breaker. In manual closing, effort is applied to the mechanism through a series of levers and linkages so that the force of the springs in the mechanism is overcome and the contacts closed, latching the breaker. This may be done with a handle permanently mounted on the breaker or by means of a detachable handle. Figure 1 shows an oil circuit breaker electrically-operated, Figure 2 illustrates electro-pneumatic operation of an air blast breaker, and Figure 12 shows an air circuit breaker with manual operators.

Electrically closed breakers may be either solenoid or motor operated, the former method being the most popular, since it eliminates gears and reduces wearing parts. Solenoids are usually designed for direct current operation and, where only a-c is available, a dry-disk type full wave rectifier is used for rectification.

Various control schemes are used in connection with electrically operated breakers. Because of the large currents drawn in closing, a relay is interposed between the closing contact of a switch, pushbutton, or other pilot device. This is generally called the x relay in switchgear terminology. Since the usual solenoid closing coil is designed (for economic and space reasons) for intermittent duty only, care must be taken to insure that the closing circuit is energized only momentarily. In many cases it is impossible to be sure that this condition is always observed.

To prevent too-long energization another relay, the y relay, which is operated by a limit switch on the mechanism known as the a-a switch, is added. The y relay causes the x relay to drop out and the solenoid to be de-energized as soon as the main breaker is closed. Figure 3 shows a typical closing circuit for a-c operation. Note that the closing coil circuit has two contacts of the x relay. Two contacts are used with rectifier operation and in all cases where 250 volt d-c is used. One contact is used with a 125 volt d-c supply. Severe services such as steel mills may use two contacts under any condition. In certain cases it is desirable to use a discharge resistor across the solenoid to absorb its energy after the x relay opens.

In electrically-operated breakers of vertical lift type, the rectifier, its aging resistor, and the x and y relays may be mounted on the removable breaker element. Figure 1 shows such an assembly.

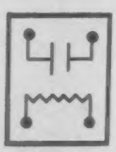
LIST OF SYMBOLS

CIRCUIT BREAKER

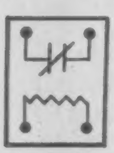
TRIP COIL

CURRENT TRANSFORMER

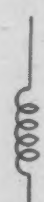
GROUND CONNECTION



RELAY, NORMALLY OPEN CONTACTS (CIRCUIT CLOSING)

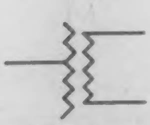


RELAY, NORMALLY CLOSED CONTACTS (CIRCUIT OPENING)

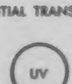


REACTOR

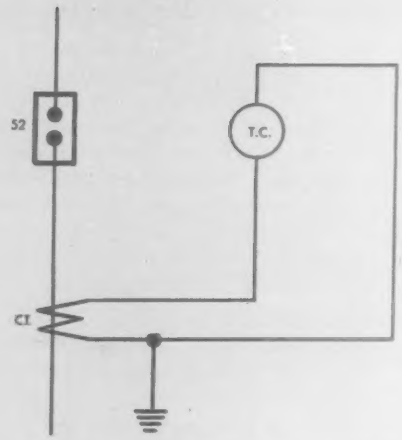
AUXILIARY SWITCH ON CIRCUIT BREAKER



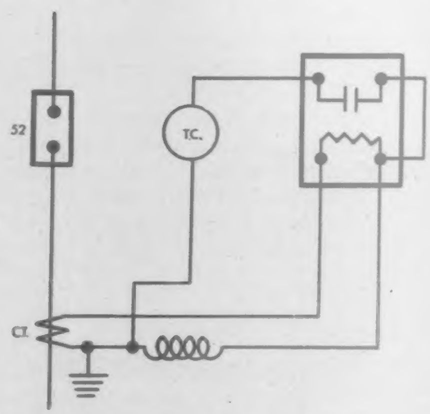
POTENTIAL TRANSFORMER



UNDER VOLTAGE TRIP COIL



Simple current transformer trip circuit. **(FIGURE 3)**



Reactor trip circuit diagram. **(FIGURE 4)**

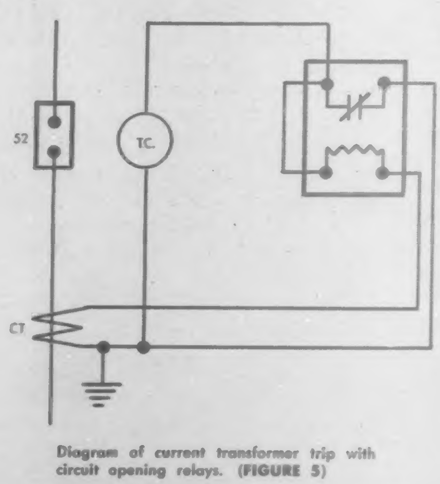
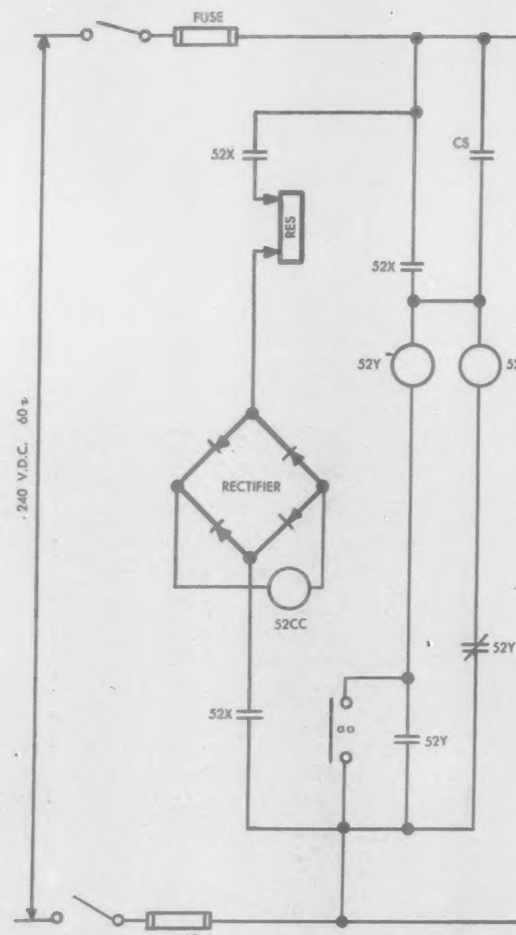


Diagram of current transformer trip with circuit opening relays. **(FIGURE 5)**



CS-C CONTROL SW. CLOSE
52CC O.C.B. CLOSING COIL

Typical closing circuit for a-c operation has x and y relays and a-a switch to limit "on" time in closing circuit. **(FIGURE 6)**

Experiments have been made with other types of rectifiers for closing, but no satisfactory method of using them has yet been found.

Although voltages as low as 12 volts d-c have been used for tripping, the large currents in closing with voltages less than 125 volt d-c create problems of current interruption in the x relay and cause larger voltage drops in the control wiring. This makes it impractical to use solenoid operators at less than 125 volt d-c or 220 volt a-c.

One of the newer methods of breaker closing is pneumatic. A pneumatic cylinder may be substituted for the solenoid type of mechanism just described, although some form of electrical solenoid valve is generally used to control the air supply to the cylinder. It is also possible to control the air supply with an ordinary hand-operated air valve. The air must be dry at all times and some form of separator to remove moisture is generally provided. To insure operation at all times a reliable source of compressed air must be supplied.

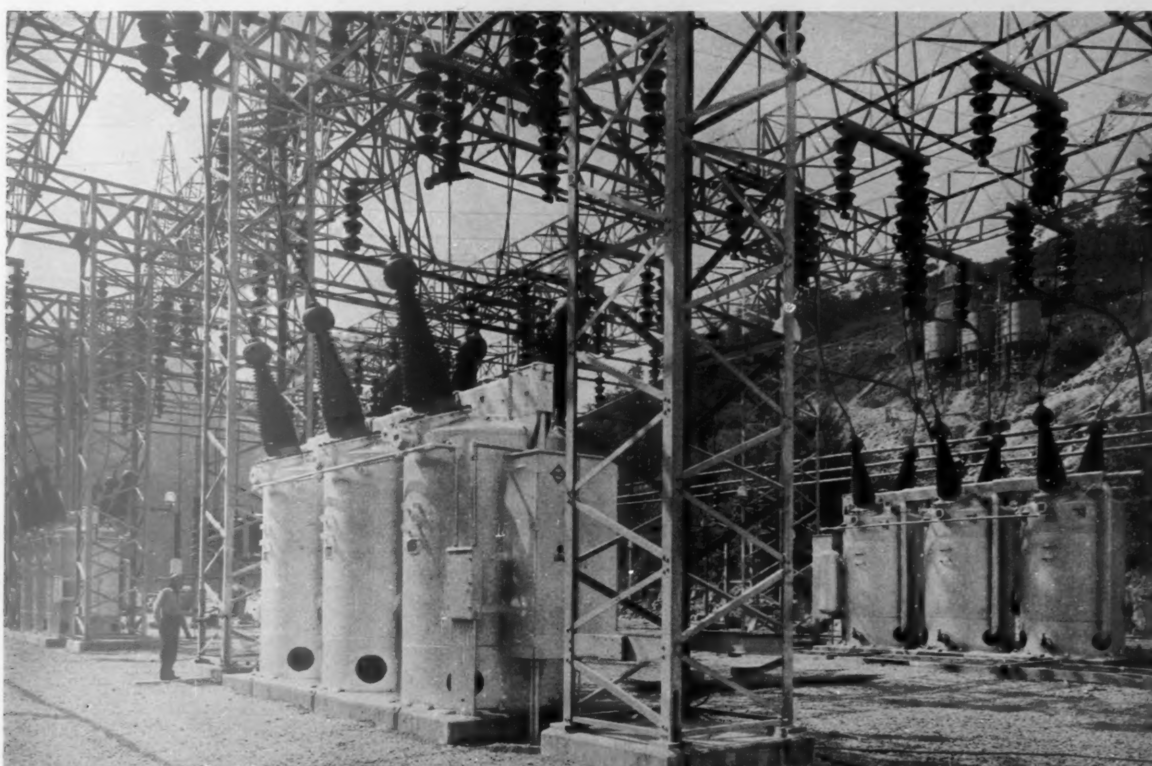
The newest adaptation of pneumatic operation comes in the closing mechanism of the air blast breaker. Air is used both to close and to trip the breaker while a blast of the same air under pressure is used to blow out the arc in the breaker arc chamber. The main contacts are opened and closed by a fast-acting pneumatic cylinder which is controlled by two pilot valves which, in turn, may be operated on voltages considerably lower than it is practical to use on a solenoid.

All methods of closing breakers can be applied to a mechanism that is trip-free. This means that if the trip coil is energized the mechanism will not latch the main contacts closed or even allow the contacts to close.

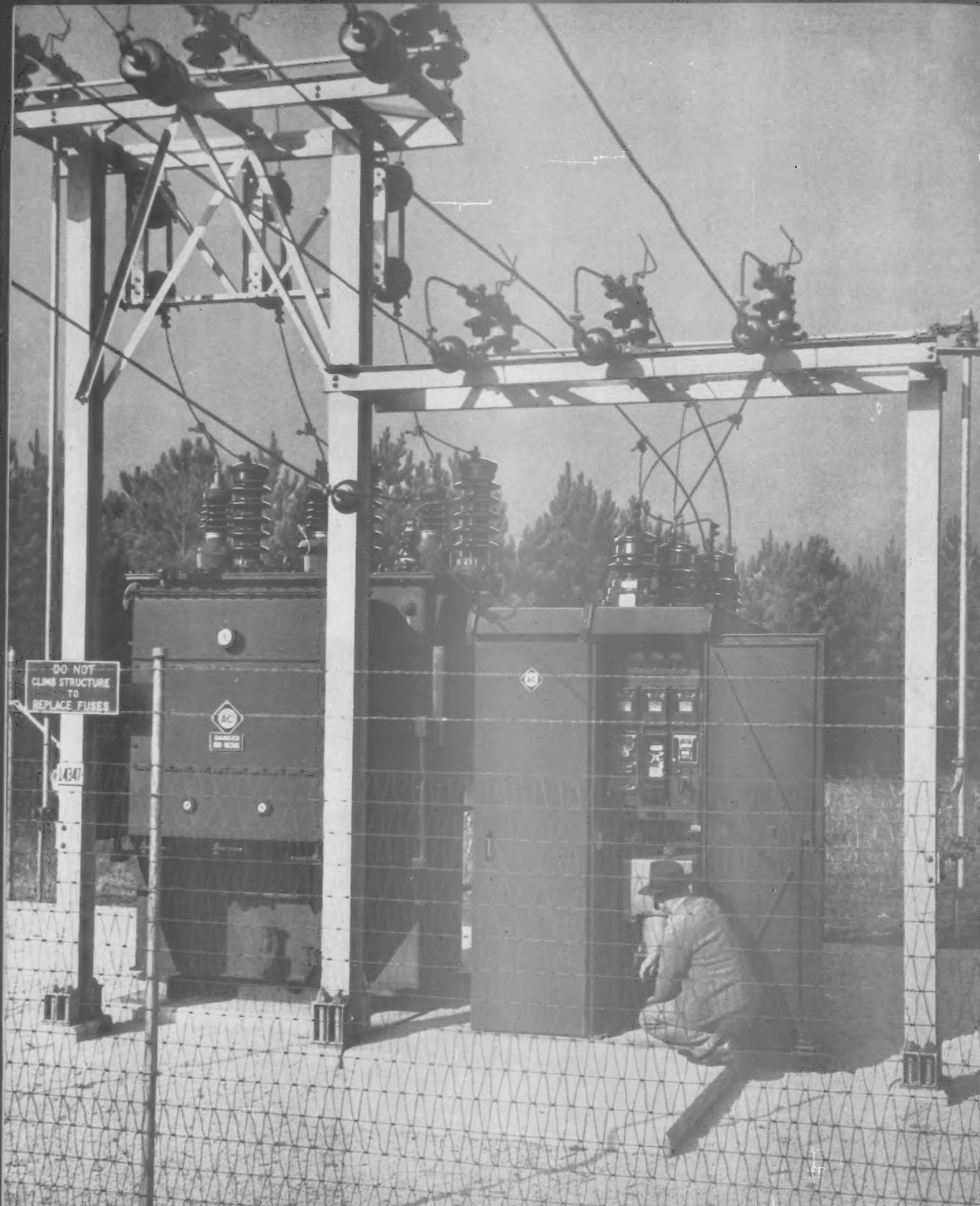
In selecting a circuit breaker for any particular application, certain basic factors, including its interrupting capacity, continuous current carrying capacity, maximum momentary carrying capacity, the current operating current and the protective features must all be considered. The last feature usually comprises the tripping mechanism and its accessories.

Tripping protects circuit

As the prime function of a circuit breaker is to disconnect a circuit safely and quickly under either normal or abnormal conditions the method used to actuate the breaker tripping mechanism is not important. Electrical circuits and equipment require protection against overloads and short circuits, abnormal voltage, power reversal, current failure, phase failure, wrong phase rotation, high temperatures, etc. This protec-



OIL CIRCUIT BREAKERS whether large or small must utilize the same basic circuits for tripping and closing the main contacts. These 161 kv pneumatically-operated breakers are installed in a large eastern generating station switchyard. Each breaker has its own air storage tank, compressor and operating mechanism. These breakers have an interrupting speed of five cycles, reclose in 20 cycles.



OUTLYING RESIDENTIAL AREAS in a southern city are served by this 1000 kva, 19.8/4.33 kv unit substation, typical of the hundreds of such units now installed or on order throughout the country. Gradually replacing the "site-erected" type of substation with its cumbersome overhead structure a unit substation such as this can be installed by a small utility crew in a day or two using only a minimum amount of space.

tion may be provided by auxiliary equipment built as part of the breaker itself, or by relays. Either method of protection can be made instantaneous or with time delay (to eliminate false operation during relatively harmless, temporary overloads and short circuits).

The simplest method of tripping a breaker consists of manually pushing a button or operating a lever which mechanically unlatches the breaker mechanism, causing the breaker to open. All other methods of tripping merely substitute a power operated device for manual effort and permit the breaker to be tripped either remotely or automatically. The source of electrical power may be the circuit protected, or some external source of power such as a storage battery.

Most low voltage circuit breakers (600 volts or less) use series overload trip coils mounted directly on the circuit breaker. When time limit features are required, inverse time limit dash pots or some similar feature are used. For most circuit breakers, instantaneous direct tripping from current transformer secondaries is the simplest method of automatic overload tripping. The current transformer secondary is connected directly to the trip coil, as in Figure A. Time delay may be added as for low voltage breakers. The number of current transformer trip coils used for common types of circuits can be determined by the following table:

Circuit	Current Transformers and Trip Coil
1-phase, 2-wire	1
2-phase, 3-wire	2
2-phase, 4-wire	2
2-phase, 5-wire	4
3-phase, 3-wire	2
3-phase, 4-wire	3

Where more accurate tripping of breakers on overloads are required, relays are interposed between the current transformers and the trip coils. Two methods of doing this where the energy from the current transformer secondaries is to be used are the reactor trip, and the use of circuit opening relays. Reactor trip is shown schematically in Figure 4.

This method of actuating current tripping is often used where no separate source of power is available. On outdoor high voltage circuit breakers, bushing type current transformers, either one per pole or two connected in series may be used, with a circuit closing type of overcurrent relay either instantaneous or time delay, a suitable reactor and trip coil. This equipment on outdoor breakers is normally mounted in a cabinet with the mechanism.

This same method is utilized for indoor breakers on lower voltages where standard wound-type current transformers are used. Here it is also possible to employ circuit opening relays. Figure 5 shows this method.

The relay is shown connected to the current transformer secondary with its circuit-opening contact shorting out the trip coil. When the relay is energized at a preset value its contacts will open, energizing the trip coil and tripping the breaker. In this type of application the contact must withstand any heavy secondary currents due to short circuits. It is particularly satisfactory for a-c tripping where no separate d-c tripping source is available. In general, when the current transformer secondary current with this method is too great for the contacts of the circuit opening relay, an auxiliary relay is used. Figure 6 shows such a scheme.

Chief disadvantage of tripping by means of a circuit-opening type of relay is the heavy burden imposed on the current transformer. A high capacity current transformer is therefore required.

An automatic undervoltage tripping attachment can be used where undervoltage protection is required as in cases where circuit breaker tripping follows a power failure. For 600 volts and below, the coil of the device is shunted directly across the line. On higher voltages the coil is in the secondary of a potential transformer. The plunger of the attachment holds the mechanism of the circuit breaker in a latched position. Release of the plunger, when the voltage falls below a predetermined value, either instantaneously or with time delay causes the breaker to trip.

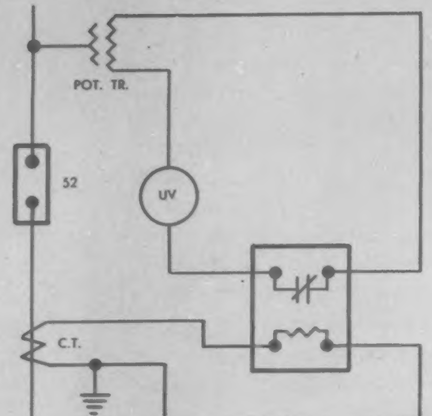
The undervoltage device may also be used to trip the breaker upon short circuits. Two methods are shown in Figures 7 and 8. Breakers may also be tripped by a variation of this method with tripping taking place on overvoltage rather than undervoltage.

Shunt trip coil is used most

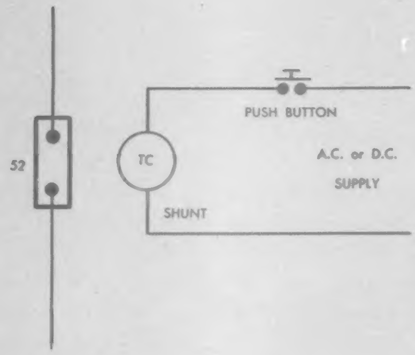
One of the most common types of tripping employs a shunt trip coil. This method is similar to that used where current from the secondary of a current transformer directly energizes the coil except that the coil is wound as a protective device. It may be designed for either 12, 24, 48, 125 or 250 volts d-c or 110, 220 or 440 volt a-c. It may be energized by a pushbutton as in Figure 9, or any type of protective relay or device. Figure 10 shows a connection with an overcurrent relay.

Applications of the shunt trip coil to the many different relays used for circuit protection can be found in descriptive literature on any protective relay. Selection of the type of relay to be used must be based on a study of the circuit conditions and the types of trouble likely to be encountered.

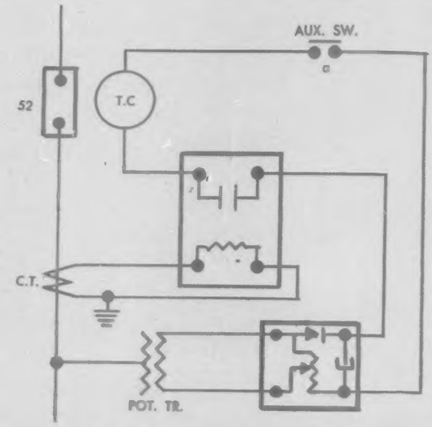
A special device known as a capacitor trip device is sometimes used with the shunt trip coil. Here a capacitor is charged through a half wave rectifier from a source of alternating current potential and then discharged through a shunt



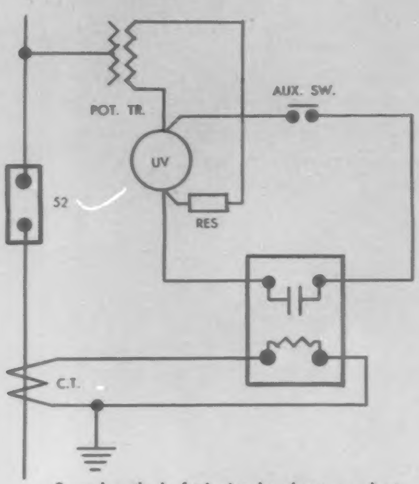
Automatic undervoltage device trip coil with circuit opening relay trips breaker upon short circuits or when line voltage fails. (FIGURE 7)



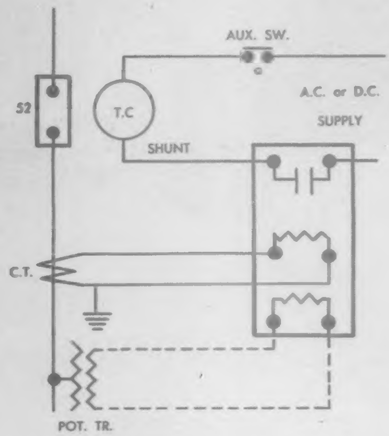
Shunt trip coil is most common type of tripping. It is here energized by a pushbutton. (FIG. 9)



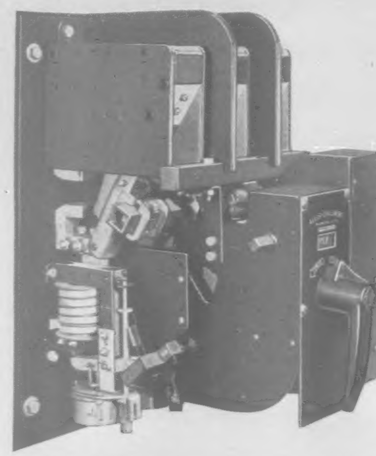
Shunt trip coil sometimes uses capacitor trip device. Circuit is simple. (FIGURE 11)



Second method of tripping breaker upon short circuits uses undervoltage trip with closing relay and auxiliary switch. (FIGURE 8)



Shunt trip coil is energized by an overcurrent relay in this arrangement. (FIGURE 10)



THIS AIR BREAKER rated 600 amp, 600 volts a-c, illustrates manual operation construction. Overload trip is at right. (FIGURE 12)

trip coil when the breaker should be tripped. Typical connections are shown in Figure 11.

The capacitor is chosen large enough to trip a breaker twice without recharging, making it useful where instantaneous reclosing is used on distribution feeders. In some cases a small neon pilot lamp is connected across the capacitor to give a visual indication of the stored energy available for tripping the breaker. Its disadvantage is that the condenser will rapidly discharge if the source of power charging the condenser is shut off, making it impossible to trip the breaker. In addition, the capacitor charging time required after power restoration is increased.

Recently circuit protective relays utilizing electronic devices have been developed to activate the shunt trip coils of circuit breakers. Such relays perform the functions of most of the ordinary types of circuit protective relays, and offer in many cases the advantages of small size together with more sensitive and faster operation. Acceptance of such devices has been slow because of a reluctance to depend on devices which are relatively fragile, subject to gradual deterioration in addition to the tube replacements required at certain intervals.

Only an outline of the more commonly used methods of tripping and closing circuit breakers and the devices necessary has been presented here. It is obvious that no one method is best, but that each has its place. In general, the method that is the simplest mechanically and electrically will give the greatest satisfaction, providing, of course, that it meets all of the operational requirements.

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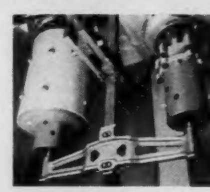

NEW 5 CYCLE dynamic (single break) "Ruptor" includes 2 devices per pole. "Ruptor" limits arc energy release . . . helps to maintain dielectric strength of oil in tank. Electrostatic shield, left, increases insulation factor between contacts and tank.

1—Like arrows from a bow, contacts open lightning-fast upon release of stored energy in powerful accelerating springs!

2—Like a tornado, pressure created by arc swirls oil through helical throat, developing great oil turbulence in "Ruptor" . . . quenching arc and clearing arc path . . . interrupting circuit in 5 cycles or less from energization of trip coil.

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